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Thermal Bridging in External Walls: Stage Two

Verney Ryan, Guy Penny, Jane Cuming (Part One only) and Mal Riley (Part One only)

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1222 Moonshine Rd, RD1, Porirua 5381
Private Bag 50 908, Porirua 5240
New Zealand
branz.nz

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Thermal Bridging in External Walls: Stage Two

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About This Report

Title
Thermal Bridging in External Walls: Stage Two

Authors and Researchers

Verney Ryan, Guy Penny, Jane Cuming (Part One only), Mal Riley (Part One only),

For and on behalf of Beacon Pathway Inc.

Reviewer
Andrea Blackmore, Beacon Pathway

Abstract
This report outlines the results from the second stage of the 'Thermal Bridging in External Timber-Framed Walls' project, funded by the Building Research Levy. Stage Two followed the finding that the percentage of framing in standard New Zealand 90mm timber walls was much higher than generally assumed and focused more deeply on the causes, impacts and potential solutions to the high percentages of timber framing and thermal bridging encountered. The research explores the drivers for the rates of framing identified during design, detailing and frame and truss manufacturing; the impacts of the current percentages of framing alongside uninsulated weak points and thermal bridging issues and the effect these have on wall R-value; and advanced framing and insulation solutions to address the range of issues identified.

Reference
Ryan, V., Penny, G., Cuming, J. (Part One only), Riley, M. (Part One only). (2021). Thermal Bridging in External Walls: Stage Two. Report Wall/4 by Beacon Pathway.

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Executive summary

This report outlines the results from the second stage of the Thermal Bridging in External Timber-Framed Walls project, funded by the Building Research Levy. Stage One established that the average percentage of timber framing in external walls in residential new builds is over 34%, much higher than the 14-18% generally assumed by regulators and within industry. The results strongly indicated that the content of timber framing is at such high levels that the increased thermal bridging compromises the performance of walls and may mean that designed R-values are not being achieved.

Stage Two focused more deeply on the causes, impacts and potential solutions to the high rates of timber framing. The research was broken down into three parts:

1. **Exploring drivers for the current percentages of framing** – the team worked with frame and truss detailers to identify the drivers of the high percentages of framing and explore optimisation of typical design and construction.
2. **Deepening our understanding of the impacts of the higher percentages of framing encountered -** assessing and quantifying the impact of both the high framing ratios and the identified weak points/blind spots on the performance of the thermal envelope through modelling.
3. **Advanced framing and insulation solutions** – identifying advanced framing and insulation options and holding a workshop to explore whether these could be adapted to modify existing 'typical' framing solutions.

Part One: Exploring drivers for higher framing percentages

In Part One, a simple standard housing design was analysed with variables covering different framing practices, framing spacing and cladding. Analysis showed that there is no single factor that drives the higher rates of framing; it is more a case of 'death by a thousand cuts' with each variable adding small percentages of timber on top of others.

Importantly, analysis of current detailing techniques suggests that there is little in the way of 'unnecessary' timber being added to framing. Each piece of 90mm x 45mm timber is added to the frame and the wall for valid regulatory and practical reasons - for structure, weathertightness, and fixings for cladding, linings and additional fittings.

The research team worked with one of New Zealand's most experienced frame and truss (F&T) detailers to explore how much the timber framing content could be reduced within the current confines of existing standards, regulations, specifications, cladding types, and construction requirements. Even with a relatively simple house design, and utilising several expert workarounds, the final percentage of framing could not be reduced from the original 'basic' detailing to a level below a 25% percentage of framing.

One of the key findings is that, despite the skills of an experienced detailer working to optimise framing, it was a significant challenge to even get below a percentage of framing of 27% on this relatively simple single storey house design.

The research indicates that optimising the percentage of framing in standard 90mm walls will not lead to a sufficient enough decrease in percentages of framing (and thermal bridging) to achieve the intention of basic NZ Building Code construction R-value minimums.

Part Two: The impacts of high framing content, weak points and blind spots

In Part Two, five sample houses (all complying with the NZ Building Code) were modelled to quantify the as-built wall R-values, the impact of the weak points on R-values and then again the R-values of a reduced percentage of framing of 25%.

The results showed the overall thermal resistance of external walls (as-built via modelling) is well below recommended levels set out in NZ Building Code Clause H1/AS1 and also below the required minimum of R1.5 set out in Building Code Clause E3/AS1. Wall panels with large areas of thermal bridging and a variety of weak points resulted in excessive heat loss and therefore present a condensation and mould risk.

The largest single increase in wall construction R-value is attributed insulating the floor slab edge on single level houses which_improves the whole house wall construction R-value by around **40%.** Upgrading the five typical weak points together produces a much smaller increase in wall construction R-values; for walls with R2.2 insulation installed, the increase is **11%.** When the five weak points and external floor slab edge insulation is addressed, the increase in average whole house wall construction R-value is 55% (R2.0 insulation), 58% (R2.2 insulation) and 68% (R2.8 insulation). The majority of the increase (80%) is due to the slab edge being insulated.

Limiting the percentage of wall framing to 25% would only result in an overall wall R-value increase of 6% for R2.0 insulation and 8% with R2.8 insulation. This is still well below the ***intention*** of NZ Building Code Clause H1/AS1 and only achieves NZ Building Code Clause E3/AS1 (minimum R1.5) with R2.8 insulation.

Given the challenges involved in reducing framing percentages and the relatively small R-value gains of reduced framing ratios in a typical 90mm stud wall, reducing framing on its own is a limited strategy. Similarly, increasing insulation to R2.8 and applying upgrades of five common weak points on their own will not produce walls with construction R-values over R1.8, even with framing limited to 25%.

Part Three: Advanced framing and insulation solutions

In Part Three, an interactive online webinar (a recording is available here: https://youtu.be/_altm5o6jcA) generated discussion amongst industry and government stakeholders on possible solutions and real-world examples of systems that have been designed, consented and built. Most of the construction approaches attempted to overcome issues relating to thermal bridging through the application of a 'second skin' of insulation over a reasonably standard 90mm stud wall.

Most solutions identified were being used in houses already under construction, giving confidence that they are buildable. Examples provided by the Superhome Movement and Oculus, of multiple projects utilising an external layer of insulation to overcome thermal bridging, suggest that the affordability of these solutions has also been addressed. The identified solutions appear to be feasible from a compliance point of view; all of the systems showcased have been through a variety of consenting and approvals process. It would be worthwhile pursuing the additional work required to deliver them as acceptable solutions within the parameters of the current compliance regimen.

Discussions during the workshop, and subsequently with a variety of industry stakeholders afterward, suggests that for these solutions to be adopted widely and achieve uptake at scale throughout New Zealand, a much more involved and wider industry/government collaboration is warranted.

Key learnings

- The **average percentage of timber framing** in external walls in residential new builds is **over 34%,** much higher than the 14-18% generally assumed by regulators and within industry.
- The content of timber framing is at such high levels that **the increased thermal bridging compromises the performance of walls** and may mean that designed R-values are not being achieved.
- There is little in the way of unnecessary timber being added to framing. From a structural and weathertightness point of view **the framing is necessary and not 'excessive'**. However, from a thermal perspective, modelling of typical houses shows that the amount of framing, and therefore thermal bridging, in standard 90mm walls is resulting in construction R-values that are much lower than appears to be the intention of New Zealand regulations dealing with thermal performance and energy efficiency.
- This research demonstrates that standard 90mm timber frame construction (complying with the NZ Building Code using definitions outlined in NZS 4218 and H1/AS1) produces typical new build houses with **whole wall construction R-values that vary between R1.2 – R1.4, even with R2.8 insulation installed**. This highlights a **sizable performance gap** between the intended R-values designed to fulfil NZ Building Code H1/AS1 compliance (R1.9/R2.0) and actual whole wall construction R-values. Apart from poor energy efficiency, walls with construction R-values below R1.5 are much more likely to develop condensation and mould. In simple terms, our walls are not as effective at keeping us warm, nor as healthy, as we might have assumed.
- Through adoption of simplified 'clear-wall' definitions, it could be argued that **NZS 4218 and NZ Building Code Clause H1/AS1 under-represents the levels of thermal bridging** that is, in reality, resulting from standard NZ construction of 90mm timber-framed walls.

- Efforts to reduce the percentage of framing through optimisation of the detailing process have shown that it is very **difficult to get below 25% framing in a wall**- even for a relatively simple single storey dwelling of modest dimensions.
- This research highlights that, even if the percentage of framing could be reduced to 25% (a big challenge), and even if insulation R-values are improved and even if they could be installed correctly, and even if all the weak points are dealt with, **these still would not be enough to overcome the negative effects of thermal bridging** and improve construction R-values sufficiently to achieve the intentions of NZ Building Code Clause H1/AS1 which calls for wall construction R-values above R1.9/R2.
- An **alternative approach**, and one that will resolve many of the issues highlighted above, is to **install an additional thermal layer on the inside or outside of the existing wall system**. This creates a thermal break between the timber framing and the external environment as well as providing space to increase the thickness of the insulation.
- A new approach to construction of walls is required - and some promising examples are being explored. A **collaborative and collective effort across industry and government** is required to design and implement a better wall construction methodology in New Zealand.

Introduction

This report outlines the results from the second stage of a Building Research Levy-funded project which examines the core issues of thermal bridging in walls of new residential houses in New Zealand.

Stage One of the 'Thermal Bridging in External Timber-Framed Walls' project (the 'Wall Project') measured the percentage of framing in modern construction through a case study approach of 47 newly constructed dwellings spread throughout Auckland, Christchurch, Wellington and Hamilton[1]. The results showed that the average percentage of timber framing compared to the area of the wall is above 34%. This is much higher than the 14 – 18% framing content generally assumed by both regulators and the industry. Indeed, the results strongly indicated that the content of timber framing in external walls in residential new builds is at such high levels that the increased thermal bridging compromises the performance of walls and may mean that designed R-values are not being achieved.

The research also highlighted significant weak points and blind spots in key aspects of current house construction. These 'defects', including uninsulated corner junctions, uninsulated mid-floors, uninsulated interior to exterior wall junctions and areas of timber flashing, timber packing and blocking, compromise the performance of the thermal envelope.

This report provides results and discussion from Stage Two of Beacon's programme of work which delves into the causes, impacts and possible solutions to the high rates of framing and issues encountered in Stage One. Stage Two of the research explores the following three key areas:

1. **Exploring drivers of current percentages of framing** – deepening our understanding of the drivers: working with frame and truss detailers to identify the drivers of the high percentages of framing and exploring optimisation of typical design and construction.
2. **The impacts of high framing content, weak points and blind spots** – deepening our understanding of the impacts of the higher percentages of framing encountered. Assessing and quantify the impact of both the high framing ratios and the identified weak points/blind spots on the performance of the thermal envelope through modelling.
3. **Advanced framing and insulation solutions** – exploring practical ideas for improvement of the thermal envelope: identifying advanced framing and insulation options, and holding a workshop to explore whether these could be adapted to modify existing 'typical' framing solutions.

[1] *See Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2020). Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand. BRANZ external Research Report ER53 (Report Wall/3 from Beacon Pathway Inc.)*

The following key research questions developed at the outset of the project helped to frame Beacon's programme of work:

Research questions

1. *Which of the identified key drivers for high framing ratios are responsible for the largest amount of additional framing?*
2. *Can framing design be optimised to reduce wall framing ratios and, subsequently, reduce the effects of thermal bridging?*
3. *What are the modelled thermal performance impacts of the higher ratios of framing encountered when compounded by the weak points and blind spots in the thermal envelope that have been identified in typical current construction practices?*
4. *What are the practical advanced framing solutions in new build construction that can improve thermal performance of timber frame walls?*
5. *Are these solutions buildable, cost effective and feasible from a compliance point of view?*

How to read this report

This report is split into three interrelated parts as they pertain to the identified key areas above. Each stream of work was conducted in parallel, with each one informing the other, but the three parts can be read independently and have separate discussion and conclusion sections pertinent to the detailed findings from that piece of work. At the end of this report, a concluding summary helps to weave the three sets of findings together and highlights what was learnt in the course of this research.

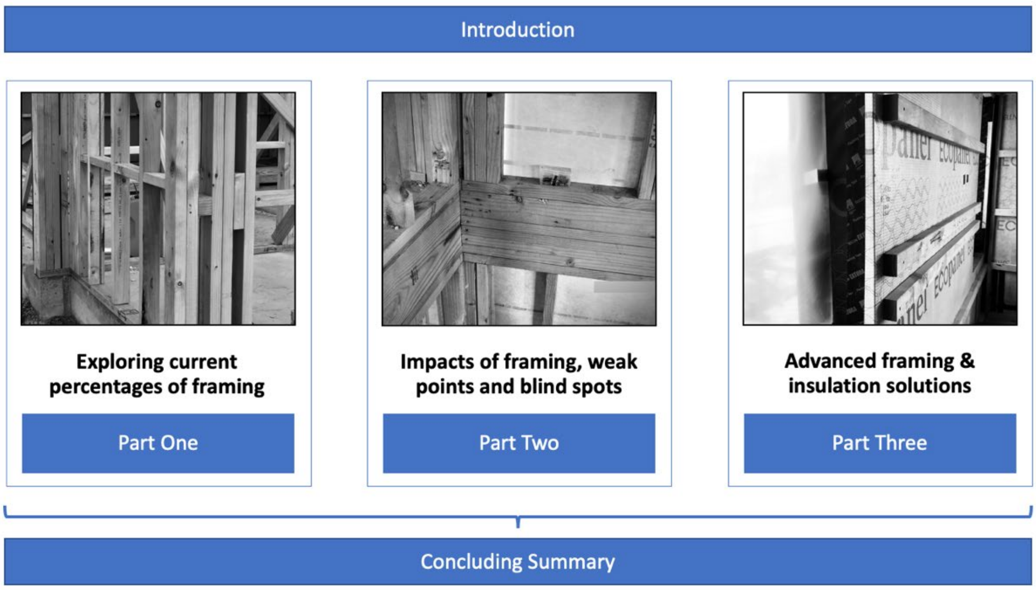


Figure 1: Diagram showing the structure of this report in three parts

Framing and thermal bridging definitions – an explanatory note

This research builds from the first stage of Beacon's research exploring 47 case study dwellings. The original project was, in part, inspired by anecdotal evidence that suggested that the levels of framing currently found in New Zealand construction, and consequential thermal bridging, were *higher than assumed* by regulators and industry (including designers, builders, engineers etc). The robust level of data collection and on-site clarification highlighted the value of being on site and seeing what was going on in construction in 'the real world' as opposed to modelling or making assumptions based on a 'nominal wall'.

The Stage One report explains in some detail how aspects of the NZ regulatory system define construction R-values and a repetition of that explanatory discussion is warranted here as the foundation for some of the concepts explored in this report. Readers are encouraged to re-visit the Stage One report to get a better understanding of these issues:

- Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2020). *Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand*. BRANZ external Research Report ER53 (Report Wall/3 from Beacon Pathway Inc.) (available from https://www.branz.co.nz/pubs/research-reports/er53/).

As covered in that Stage One report, and repeated here, it is worth noting that the instructions for calculating construction R-values under NZS 4218 are somewhat ambiguous and **do not sufficiently account for the full effects of thermal bridging within the building envelope**. Crucially, when applied to modern frame and truss wall panels, the definitions of what needs to be counted **exclude a significant number of the framing elements that contribute to thermal bridging and heat loss**. This is seen in two main sections of NZS 4218 that deal with construction R-values in Section 3.2 and linked to Section 2 dealing with the definitions; as per the following:

Construction R-value

The construction R-values of building elements shall be calculated using the typical area described in the definitions.

The construction R-value for walls, roofs, floors, and doors may instead be calculated including the effect of openings and corners, lintels, sills, additional studs, and so on.

Figure 2: Text relating to the definition of Construction R-value - S3.2 of NZS 4218 (2009)

Construction R-value	The R-value of a typical area of a building element (for further information see 3.2)
For walls and roofs	The R-value of a typical area of the building element excluding the effects of openings and corners
For framed walls	This includes studs, dwangs, top plates, and bottom plates, but excludes lintels, additional studs that support lintels, and additional studs at corners and junctions

Figure 3: Text relating to the definition of walls (excluding key framing elements) - S2: Definitions of NZS 4218 (2009)

The text referring to 'framed walls' above specifically **excludes** lintels, supporting studs, and studs at corners and junctions. With these elements removed from the equation, the resulting calculation provides a ***version*** of a 'construction R-value' that only applies to the 'clear wall' section of the wall, rather than the 'whole wall' which includes all framing elements present in the wall and therefore accounts for the increase in resulting thermal bridging. As a result, 'construction R-values' as determined by NZS 4218 overstate the R-values of the actual wall. Using 'whole wall' construction R-values gives a more accurate indication of the thermal performance of a wall.

Toward the conclusion of Stage One of the Wall Project research, BRANZ suggested undertaking some modelling using a recently developed R-value calculation tool and utilising results from a number of examples of the collected case study data to ascertain how overall wall R-values might be affected by higher percentages of framing. This was useful to the research team in determining the **difference between the *actual* 'whole wall' framing encountered on site when compared to NZS 4218 definitions.**

The drawing below[2] illustrates the difference between the 'whole wall' framing installed (i.e., on site) in a single case study wall panel when compared to how the wall is set out in the definition provided in NZS 4218 - which effectively allows the user to **ignore the thermal bridging of lintels, trimming and double studs** etc. (i.e., the definition is descriptive only of the 'clear wall')

[2] ***R-value modelling and images courtesy of Ian Cox-Smith, BRANZ***

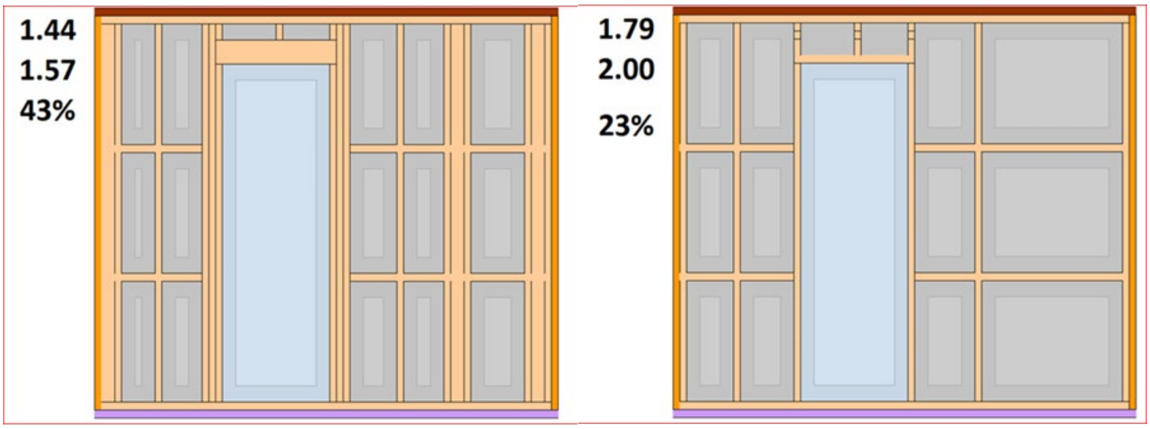


Figure 4: Actual timber framing (left) compared to allowable definitions under NZS 4218 (right)

The figures shown in the top left of each drawing indicate the following; firstly the achieved R-value with R2.0 insulation in the voids, then the achieved R-value with R2.8 insulation installed (the maximum that is currently achievable in a 90mm cavity), and then the third figure describes the percentage of framing that make up that wall panel as it is drawn.

In this single example, the first illustrated panel (left hand side), is a realistic representation of what was installed on site, has a net percentage of framing of 43% (the opening has been removed from the calculation). With R 2.0 insulation in the wall, the wall would only deliver a construction R-value of R1.44 (due to the effects of thermal bridging). With higher R 2.8 insulation in the wall, the construction R-value only marginally exceeds the required minimum construction R-value of R1.5 set out in clause E3 of the NZ Building Code. It is worth noting that, even with the higher R-value of insulation installed (R2.8), the construction R-value is below the minimum required construction R-value of R1.9 for walls in the Auckland climate zone (the ***intention*** of NZ Building Code H1/AS1).

The second illustration (right hand side) is of the same wall panel, but only shows framing that is required to be counted using the definition outlined in NZS 4218 when calculating wall R-values. In relation to thermal bridging, the **simplified** approach set out in NZS 4218 states "*This includes studs, dwangs, top plates, and bottom plates, but* ***excludes*** *lintels, additional studs that support lintels, and additional studs at corners and junctions*". Using this definition, the wall can be redrawn as per the image on the right and this then indicates a percentage of framing of only 23%. Interestingly, even with this definition, the required resulting minimum construction R-value of R1.9 for Auckland is only achieved, in this example, with the addition of R2.8 insulation in the voids. With the R2.0 insulation, it only achieves a construction R-value of R1.79. It is also important to note that these calculations and models do not account for any losses due to poorly installed insulation or uninsulated spaces, uninsulated corners etc. Were these weak points to be accounted for, this would further reduce the ***actual construction R-value*** of the illustrated walls.

Through adoption of these simplified definitions, it could be argued that NZS 4218 under-represents the levels of thermal bridging that are, in reality, resulting from standard NZ construction of 90mm timber-framed walls. Certainly the use of the term '**construction R-value'** in this instance is somewhat misleading. Potentially, it also further compounds common misconceptions of the overall impact of thermal bridging, and may be the reason that many people are surprised by the lower R-values of more accurate modelling of the **actual construction R-value** discovered by the research and outlined in this report (especially in Part Two). Furthermore, the simplified definitions in NZS 4218 of 'typical clear wall areas*'* may help to explain where the false picture has been painted that our walls are in the region of 14-18% framing, whereas Stage One of the Wall Project research provided evidence to show that, in reality, 'whole wall' percentages of framing are approximately double this.

Simply put, industry has been operating under an assumption when using the schedule method outlined in NZS 4218 that a true 'construction R-value' can be attained through a simple calculation of typical 'clear wall' areas with simple inputs of stud and dwang (or nog) spacing. Yet the site-based research conducted in Stage One of the Wall Project highlighted that areas of 'clear wall' make up only a small part of wall panels with openings in them. In reality, most walls and wall panels are made up of a complex arrangement of studs, nogging, openings and supporting structures – all of which add to heat loss through thermal bridging and should be accounted for when calculating the thermal performance of our buildings.

In terms of clarifying definitions, one suggestion might be to revisit NZS 4218 definitions and rename the **construction R-value** resulting from calculating a typical section of 'clear wall' and instead call it a '**simplified estimated clear wall R-value'**. It may also be beneficial to introduce the term 'whole wall' to the NZS 4218 definitions for completeness.

Part One

Exploring drivers of current percentages of framing

Part One: Exploring drivers of current percentages of framing

This part of the research deals with deepening our understanding of the drivers of the higher-than-assumed ratios of framing encountered in Stage One of the Wall Project. The research undertaken in this part of the overall project was aimed at answering the following key research questions:

1. *Which of the identified key drivers for high framing ratios are responsible for the largest amount of additional framing?*
2. *Can framing design be optimised to reduce wall framing ratios and, subsequently, reduce the effects of thermal bridging?*

The core concept of this part of the research was to work alongside frame and truss detailers to identify the drivers of the high percentages of framing, and to explore the opportunities for the optimisation of typical design and construction.

1 Method

Previous research undertaken by Beacon in Stage One of the Wall Project identified a range of drivers for higher-than-expected percentages of framing including: cladding requirements (type and orientation), roof weight and material, window size and placement, number of levels, wind zone, designer preference and panel dimensions. This next phase of the research aimed to deepen our understanding and to highlight which of the identified key drivers for framing ratios are having the most impact on additional timber added. There was also scope to assess whether design can be optimised to achieve lower framing ratios.

The previous Beacon research looked at 47 as-built houses to determine the percentage of framing in exterior or insulated walls. The houses were a variety of different shapes and sizes, single or two storey, in different wind zones, with a range of different claddings and were designed using a combination of specific design or standard 3604 framing set-out. This made analysis of the variables that might drive higher percentages of framing challenging.

In order to more discreetly test the range of variables that might drive higher percentages of framing, a simple single storey model house designed within the scope of NZS 3604 was developed. This modest house plan was explored to look at the difference variables, such as wind zone and claddings, make to exterior wall framing percentage and volume of timber used (typically, frame and truss plants will report cubic metres of framing used in each wall panel). What norms and restraints govern framing? How much can the percentage of framing be reduced by through making simple changes?

1.1.1 The frame and truss process

It is estimated that over 95% of New Zealand houses are constructed using timber frames manufactured off-site at a frame and truss manufacturing plant (F&T)[3]. Frames are manufactured in a factory setting and stored on site until the builder is ready to take delivery. Each layer of framing (bottom storey frames, upper storey frames, trusses) is delivered separately. Frames are loaded by forklift onto a truck for delivery to site. Once delivered and off-loaded by hi-ab, frames are typically manually lifted into position by the builders.

Prior to manufacture and generally contracted by the builder, detailers working for F&T manufacturers convert plans and specifications into working drawings which 'detail' every component of the frame for manufacture. In development of the wall panel layouts, detailers factor in constraints such as available timber lengths, truck dimension (this would typically affect truss dimensions rather than frame), forklifting and weight of framing to be manually lifted on site.

1.1.2 Identification of suitable case study house design

The research team explored a number of different house designs and refined these down to a reasonably standard and simple 116m^2 house plan on a 25 degree hip roof, 600mm soffit width, nominal 2400mm walls. The bathroom wall was popped out, and porch recessed to create internal corners.

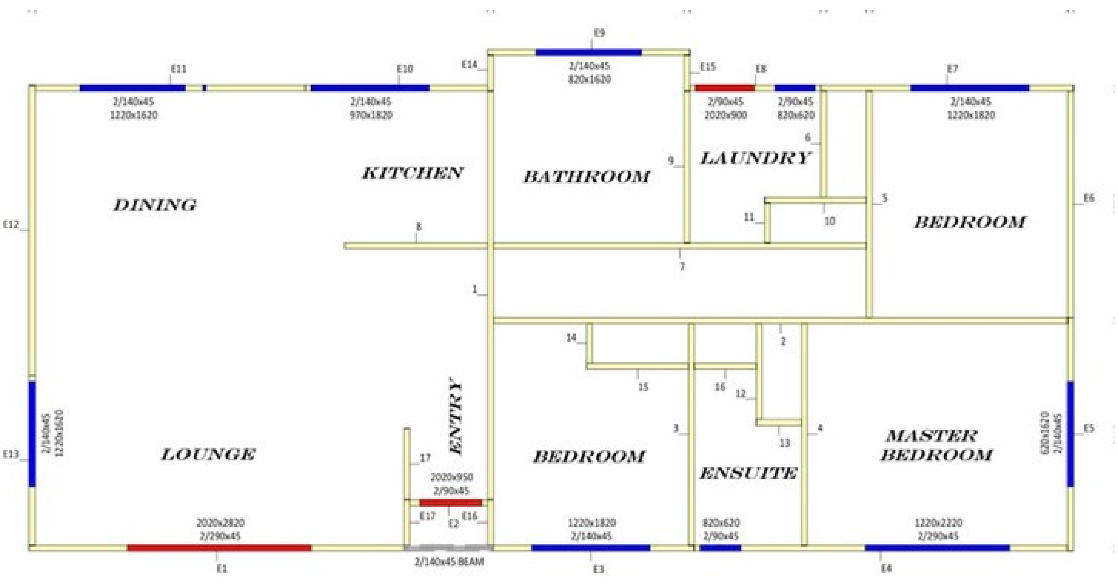


Figure 5: Simplified house plan design for use in detailing analysis (modified from original)

This was the baseline design used by an expert detailer to develop working drawings for different wind and cladding scenarios for a house located in Auckland. Utilising cubic volume of timber estimates from the detailing software, the detailer was able to derive the actual volume of timber in each framing

[3] This figure was provided as an estimate from a number of different F&T manufacturers and representatives from the Frame and Truss Manufacturers Association (FTMA) who quoted figures as high as 96% of supply to the residential sector

scenario. This information, coupled with data and evidence gathered in Stage One of the Wall Project, allowed the research team to generate average percentages of framing across the sample (this is outlined in further detail in Part Two of this report – see section 2.1.3.1)

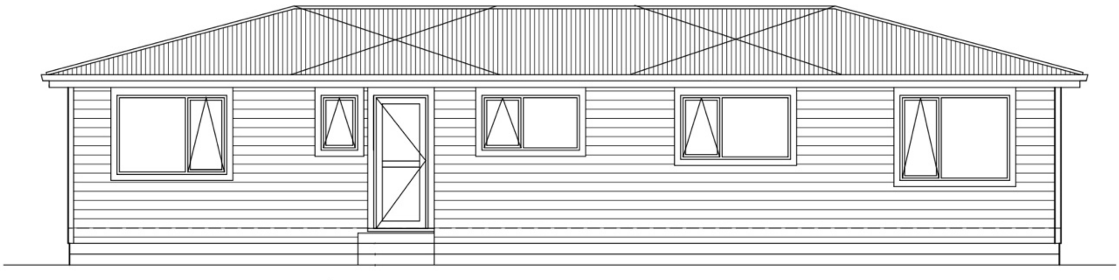


Figure 6: Simplified house design in elevation (modified from original)

1.1.3 Industry preferences and norms

From the outset of the investigation, a set of agreed industry preferences and norms were observed. These are influenced by standards and commonly accepted approaches as well as the more general 'culture' developed within the industry as 'the way things are done' and these included the following:

- SG8 grade radiata: The grade of timber depends on growing conditions and this is the grade which most closely matches the radiata grown in NZ. NZS 3604 gives preference to SG8 tables although SG6 and SG10 tables are also available. SG8 grade radiata is readily available and has become the industry norm.
- 45mm width framing (not 35mm or multiples of 35mm framing): It is unclear why 35mm timber is not readily available or widely used. It is possible this dropped out of production to reduce complexity and inventory at F&T plants as multiple treatment and grade options were introduced in the 2000s.
- 3 stud external corners: This is a long-established norm within the building industry.
- 3 stud partition-to-external-wall junctions: This is a long-established norm within the building industry.
- Nogs at 800mm centres: This appears to be a well-established industry norm and may require further investigation. Illustrations of framing (e.g., BRANZ house insulation guide) commonly show two rows of nogs. Some fire-rated systems require nogs at 800mm centres and anecdotal evidence gathered during the research suggested that this may also be builder preference.
- Cladding on cavity regardless of risk score: This has become the designer norm in Auckland – further investigation is required to understand if this is driven by necessity to comply with E2/AS1, or if designers/builders are defaulting to cavity to keep it simple.

1.1.4 Framing and stud spacing

Tables in NZS 3604 determine stud spacing is at either 600mm or 400mm centres depending on wind load.

1.1.5 Framing and openings

The framing around openings (including lintel sizing) is determined by, the weight of the roof, the distance of the lintel below the top plate and the width of the window or door opening and any point loads in the structure above the window opening. None of these factors changed in the scenarios considered for this aspect of the research. All of the examples used an understud to support the lintel.

1.1.6 Claddings

A range of different cladding types were explored in order to examine the effects of cladding choice on percentages of framing. The claddings chosen were representative of common cladding types popular in modern construction and also typical of the range discovered in the original 47 case study house sample. They included brick, horizontal weatherboard, vertical weatherboard, and plywood or fibre cement sheathing with horizontal weatherboard cladding. These are a sample of acceptable solution claddings and were chosen to provide a range of framing scenarios. With the exception of brick, E2/AS1 allows for claddings to be direct fixed or fixed over 20mm cavity battens depending on how the building scores on a risk matrix. All of the cladding scenarios were detailed on a cavity regardless of risk score. This reflects observation of claddings in the Stage One of the Wall Project as well as feedback from F&T manufacturers in Auckland that cavity construction is now the norm. In practice (and as can be seen in the results below), the framing set-out for different claddings shifted the position, but not the number, of studs at internal corners; and with the exception of the sheathing option (plywood sheathing on the exterior of the studs), the only difference discovered between claddings was for different dwang/nog lines.

1.1.7 Exploring variables

After establishing the key criteria, a range of different wall panel layouts for each 'scenario' was undertaken. This was completed as follows:

1. First, the research team established the base framing percentage volume for brick and weatherboard (horizontal and vertical) and sheathing with horizontal weatherboard on a cavity over plywood or fibre cement sheathing.
2. The cladding scenarios were then optimised using three different methods; reducing nogs, reducing external corner and partition studs using a proprietary GIBFIX or MiTek Stud Saver framing system, and detailer editing (where the detailer would use his experience and knowledge to reduce framing as much as possible within the bounds of NZS 3604).
3. Utilising analysis from Stage One, a calculation methodology was devised to ascertain percentage of framing from each of the wall panel layouts. These were aggregated at the house level and the final percentage of framing calculated for each of the scenarios.
4. Finally, the detailer explored optimisation of house design and resulting wall panel design / layout through approaches such as shifting window locations, changing claddings, spacing blocking and packing to allow for insulation etc.

1.1.8 Examples of scenarios

The following illustrations show some of the different scenarios that are explored in the results covered in section 2 below. They may assist the reader in developing an understanding of the frame and truss panel production, with all of the examples below highlighting in red a single wall panel.

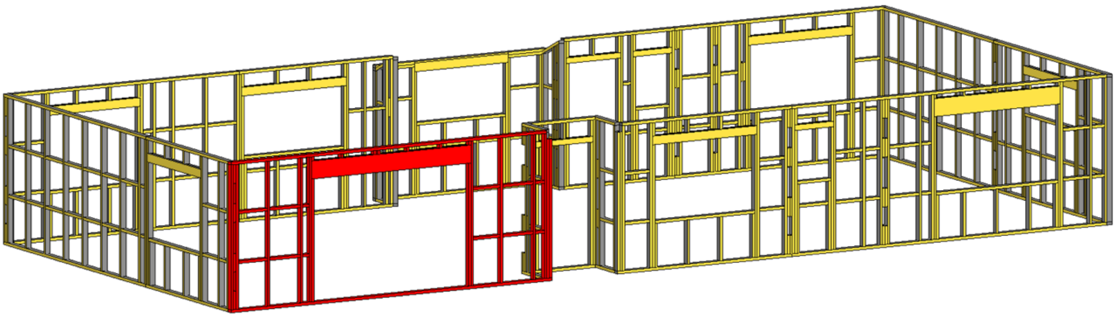


Figure 7: Typical scenario showing studs at 600mm centres and nogs at 800mm

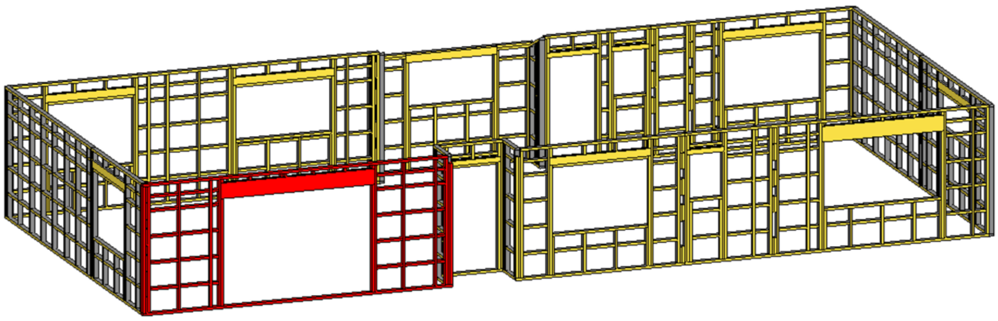


Figure 8: Scenario showing studs at 600mm centres and nogs at 480mm maximum for vertical shiplap cladding

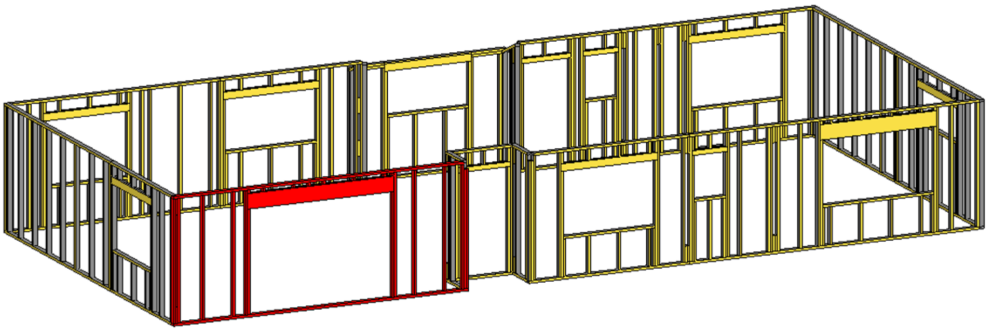


Figure 9: Scenario showing studs at 600mm centres set out for rigid air barrier (RAB) and no nogs (noting that this would be problematic for fabricator delivery)

These scenarios, as well as others, are explored in the results and discussion below.

2 Results

The following table summarises the core results from each of the scenarios explored as a variance of the standard simple house design.

The first column identifies the scenario number as well as the research label (with SH standing for Simple House), the second the cladding type, the third the specific framing variable for that scenario, and then the final three columns describe the result of the percentage of framing for the whole house using 90mm x 45mm radiata at either 600mm or 400mm stud centres and 140mm x 45mm framing at 600mm centres.

Table 1: Summary of detailing results

Scenario number	Cladding	Details	Percentages of framing		
			90mm x 45mm 600mm centres	90mm x 45mm 400mm centres	140mm x 45mm 600mm centres
1 SH#A	Brick	2 rows nogs @800mm	29.29%	31.99%	29.86%
2 SH#ADO2	SH#A brick Stud-saver** external corners only	2 rows nogs @800mm	28.63%	30.12%	29.13%*
3 SH#ADO3	SH#A Brick Stud-saver** external corners and partition walls	2 rows nogs @800mm	27.37%	29.02%	27.87%*
4 SH#ADO1	Detailer editing of SH#A	2 rows nogs @800mm	29.29 n/c	30.83	29.86%*
5 SH#K	Brick	1 row nogs @1350mm max	27.75%	30.30%	28.25%*
6 SH#KDO1	Detailer editing of SH#K brick	1 row nogs @1350mm max	27.75 n/c	29.20	28.25%*
7 SH#B	Horizontal w/bd SH#B	2 rows nogs @800mm + soffit nog	30.95%	33.82%	31.45%
8 SH#C	Horizontal w/bd SH#C	1 row nogs @ 1350mm max + soffit nog	29.35%	32.49%	29.75%
9 SH#E	Vertical shiplap w/bd	4 rows nogs @480 + soffit nog	34.12%	37.18%	34.95%
10 SH#E-M1	Vertical shiplap w/bd	4 rows nogs @480 + soffit nog + double sills	34.72%	37.78*	35.55*
11 SH#D	Plywood or fibre cement sheathing	2 rows nogs @ 800	30.44%	34.10%	30.88%
12 SH#H	Plywood or fibre cement sheathing	1 row nogs @ 1350 max	28.74%	32.48%	29.24*
13 SH#J	Plywood or fibre cement sheathing	No nogs ***	27.40%	31.01%	27.90*

*Derived by calculation using experience from similar scenarios +0.5% increase from 90mm x 45mm to 140mm x 45mm with the exception of row 10 which has been calculated by adding +0.6% to the row above **Studsaver using frame set out as per MiTek Stud-Saver or GIBFIX framing system. These are proprietary light gauge steel angles (L shaped) used to support plasterboard fixing ***Frames with no nogs/dwangs may not be able to be manufactured at F&T and may be dangerous/problematic to handle on site.

Scenario Internal code	Cladding		Percentages of framing		
			90mm x 45mm 600mm centres	**90mm x 45mm 400mm centres**	**140mm x 45mm 600mm centres**
1 SH#A	Brick	2 rows nogs @800mm	29.29%	31.99%	29.86%
			-1.54	-1.69	
5 SH#K	Brick	1 row nogs @1350mm max	27.75%	30.30%	28.25%*

Comment:

In the example above, 90mm x 45mm framing has been set out for brick cladding on 600mm and 400mm framing centres and 140mm framing on 600mm centres. Scenario no.1 used two rows of nogs which is standard in some parts of NZ. Scenario no. 5 has been detailed with one row of nogs.

For framing set out at 600mm centres and 400mm centres the percentage of framing is reduced by 1.54% and 1.69%.

Percentage reductions have not been calculated where framing has been derived by assumption, indicated by an asterix '*'.

Scenario Internal code	Cladding		Percentages of framing		
			90mm x 45mm 600mm centres	**90mm x 45mm 600mm centres**	**90mm x 45mm 600mm centres**
7 SH#B	Horizontal w/bd	2 rows nogs @800mm + soffit nog	30.95%	33.82%	31.45%
			-01.6	-1.33	-1.7
8 SH#C	Horizontal w/bd	1 row nogs @ 1350mm max + soffit nog	29.35%	32.49%	29.75%

Comment:

In the example above, 90mm x 45mm framing has been set out for horizontal weatherboard cladding on 600mm and 400mm framing centres and 140mm framing on 600mm centres. Scenario no.7 used a soffit nog and industry standard two rows of nogs. Scenario no. 8 has been detailed with a soffit nog and one row of nogs.

For 90mm x 45mm framing set out at 600mm centres and 400mm centres the percentage of framing is reduced by 1.6% and 1.33%.

For 140mm x 45mm framing set out at 600mm centres the percentage of framing is reduced by 1.7%.

Scenario **Internal code**	**Cladding**		**Percentages of framing**		
			90mm x 45mm 600mm centres	**90mm x 45mm 600mm centres**	**90mm x 45mm 600mm centres**
11 SH#D	Plywood or fibre cement Sheathing	2 rows nogs @ 800mm	30.44%	34.10%	30.88%
			-1.7	-1.62	
12 SH#H	Plywood or fibre cement Sheathing	1 row nogs @ 1350mm max	28.74%	32.48%	29.24*
			-1.34	-1.47	
13 SH#J	Plywood or fibre cement Sheathing	No nogs ***	27.40%	31.01%	27.90*

Comment

Plywood or fibre cement sheathing attached to the top plate before the soffit framing is installed will not need a soffit nog, provided the sheathing provides enough support to the horizontal cavity closer batten to stop air getting past and into the roof cavity. Note: The percentage of framing for sheet claddings are higher than the equivalent framing set out for brick. This may be explained by the detailer opting to reduce sheet cutting on site.

Moving down the rows (the 3rd column has not been calculated because two of those numbers were derived by assumption using +0.5% increase from 90mm x 45mm to 140mm x 45mm) reducing to one row of nogs reduces framing by 1.7% and 1.62% (90mm x 45mm studs at 600mm & 400mm set-out) and reducing to no nogs is similar. The total difference going from two rows of nogs to none is around 3%. It should be noted that frames with no nogs may not be able to be manufactured at F&T due to the difficulty of making, stacking and delivering frames without nogs. Similarly frames without nogs may be dangerous and difficult to handle on site.

2.2 Interpreting the results table – key findings

The following key findings can be noted from the table above:

- 90 x 45mm framing at 600mm centres ranged from 27% to 35% by volume with different cladding scenarios.
- 90 x 45mm framing at 400mm centres ranged from 31% to 37% by volume with different cladding scenarios.
- For each particular cladding scenario, reducing the stud set-out from 600mm to 400mm centres resulted in approx. 3% increase in framing by volume except for the sheathing scenario which increased wall framing by over 5%. The difference between 600mm and 400mm centres represents the 'savings' if higher grade SG10 timber is specified instead of SG8 at 400mm centres in higher wind zones.
- Increasing the framing depth from 90mm x 45mm to 140mm x 45mm at 600mm centres resulted in a slightly higher percentage of framing (approximately 0.5%). The set-out was the same and full depth nogs were used. The biggest increase was seen with the sheathing scenario which increased framing by 2.7%.
- As the core of the relatively simple structure did not change, the percentage of framing differences noted between cladding types was largely attributable to nog lines. The range for claddings with two or more rows of nogs and studs at 600mm centres was 30.44 - 34.7% and 32 - 37.18% for 400mm centres. Note, it is likely that if the research team had detailed vertical weatherboard with double sills at 400mm centres, the range would have been slightly higher.
- Vertical weatherboard had the highest percentage of framing when comparing the different cladding types. E2/AS1 requires nogs at 480mm centres for vertical weatherboards. In addition, because vertical weatherboards are nailed horizontally, it may be necessary to use a double sill to get nailing where a window support bar is used (as the bar covers the front face of the sill and cannot be nailed). Some manufacturers offer a structural horizontal cavity batten which removes the need to use nogs to fix the cladding and would move the percentage of framing back in line with horizontal weatherboard. That option has not been included in these scenarios as it is outside the scope of E2/AS1.
- The first optimisation explored a reduction of nog lines from the industry standard (or norm) of two rows of nogs between studs. This reduced the percentage of framing in the brick cladding scenario to 27.6% at 600mm centres and 30.66% at 400mm centres. The percentages of framing for horizontal weatherboard were similar.
- The second optimisation explored a reduction in corner studs and partition framing by using the MiTek Stud Saver proprietary system and resulted in nearly 3% reduction in framing using the sheathing scenario. This system requires two rows of nogs.
- Simple optimisations resulted in relatively small changes to the total percentage of framing timber.

One of the key findings is that, despite the skills of an experienced detailer working to optimise framing, it was a significant challenge to even get below a percentage of framing of 27% on this relatively simple single storey house design.

2.3 Additional observations

Over the course of completing the detailing scenarios on the simple house design, the research team noted the following additional observations which assist in an understanding of the drivers of higher percentages of framing:

1. Some detailers / architects specify a double stud under a girder truss point load even though it might only require a single stud.
2. Some detailers put a double stud at the shower as a matter of course.
3. Some architects ask for studs at 400mm centres for wet areas, presumably in case heavy tiles are installed
4. Some detailers put in a 140mm lintel for external doors even though it normally only requires a 90mm.
5. Double sills are sometimes shown on architectural details regardless of cladding, presumably for WANZ support bar (this is a window sill support bar that helps to carry the weight of the window back to the timber framing).
6. From time to time, there is a shortage of longer length timber which necessitates using shorter length timber for top and bottom plates. This, in turn, creates more wall breaks (shorter panels) and therefore additional studs.
7. Some companies change top and bottom window jack stud centres to 400mm if studs change to 400mm centres
8. Direct fix claddings must follow E2/AS1 and require a 20mm packer each side of the opening to accommodate the sill tray, especially with weatherboard cladding.
9. If joinery is full height, this presents a challenge when dealing with the soffit – the detailer may increase the lintel to suit to avoid top jacks less than 100mm. This is a factory safety hazard as the nogs can split away upon nailing. In most cases, the detailer will either increase the lintel or the factory will put in a packer to avoid the small top jacks.
10. If vertical shiplap is cedar (i.e., with exposed nailing), the detailer 'evens' the nog spacing between the bottom plate and the soffit nog so the nog spacing is equal (largely for aesthetics). This would slightly increase percentage of framing by volume if the new nog line is longer (i.e., runs below a window opening) but the effect is likely to be insignificant.
11. Currently, all scenarios in this piece of research are presuming a hip roof – if the roof was gable each end and the soffit follows the gable, the soffit nog would no longer be required on the gable walls.

3 Discussion

The process of working through a relatively simple house design with an experienced frame and truss detailer have yielded a number of interesting insights.

3.1 What the framing is doing

First and foremost, the framing has to carry all likely loads, then provide any extra framing required to attach the cladding according to E2/AS1, if that is what is specified, and the manufacturer's technical literature. Bracing and/or Fire rated systems may have extra framing requirements.

3.1.1 Structure

NZ Building Code clause B1 Structure requires "Buildings will withstand likely loads including wind, earthquake, live and dead loads (people and building contents)". B1/AS1 cites NZS 3604 as an acceptable solution with modifications which don't affect wall framing, provided the designer works to re-drawn earthquake zones in the Christchurch region. Wall framing designed and braced using NZS 3604 is deemed to comply with B1/AS1. NZS 3604 translates the live and dead loads listed above into framing via a series of tables which size framing components according to timber grade.

Referring to the single storey table 8.2 for loadbearing SG8 and looking at the columns for 2.4m stud height (see Figure 10 below), it can be seen the 90mm x 45mm stud spacing is 400mm for Extra high and Very high wind zones, then shifts to 600mm for high wind. Industry defaults mean 90mm x 45mm would be used in lieu of 90mm x 35mm at 600mm centres for lower wind zones.

SECTION 8 – WALLS NZS 3604:2011

Table 8.2 – Studs in loadbearing walls for all wind zones – SG 8 (see 8.5.1.1)

Wind zone	Loaded dimen-sion* of wall	Stud sizes for maximum length (height) of: (m)								
		2.4			2.7			3.0		
		At maximum stud spacing (mm) of:			At maximum stud spacing (mm) of:			At maximum stud spacing (mm) of:		
		300	400	600	300	400	600	300	400	600
	(m)	(mm x mm)	(mm x mm)	(mm x mm)	(mm x mm)	(mm x mm)	(mm x mm)	(mm x mm)	(mm x mm)	(mm x mm)
		(width x thickness)								
(a) Single or top storey – Light and heavy roof										
Extra high	2.0	–	90 x 45	90 x 70						45
	4.0	–	90 x 45	90 x 70						
	6.0	–	90 x 45	90 x 70						
Very high	2.0	–	90 x 45	90 x 70						
	4.0	–	90 x 45	90 x 70						
	6.0	–	90 x 45	90 x 70						
High	2.0	–	90 x 35	90 x 45						
	4.0	–	90 x 35	90 x 45						
	6.0	–	90 x 35	90 x 45						
Medium	2.0	–	90 x 35	90 x 35						
	4.0	–	90 x 35	90 x 35						
	6.0	–	90 x 35	90 x 35						
Low	2.0	–	90 x 35	90 x 35						
	4.0	–	90 x 35	90 x 35						
	6.0	–	90 x 35	90 x 35						

F&T industry generally defaults to 90mm x 45mm instead of 90mm x 35mm

Figure 10: Table modified from NZS 3604 showing defaults to 90 x 45mm framing

The results from this part of the research indicate how much timber is in the external walls of this particular simplified house when studs are spaced at 600mm and 400mm centres. It also shows the potential 'saving'; using stiffer, higher grade, SG10 would result in framing at 600mm centres in 'extra high' and 'high' wind zones. (ref Table A8.2 in NZS 3604 and shown in Figure 10 above). It should be noted there is a limited supply of SG10 timber so designers should resist specifying SG10 where it won't make any difference.

3.1.2 What is extra?

This simplified house set up as the model for this part of the research has a hip roof, therefore all of the exterior walls are load-bearing. The roof truss design has a truncated girder truss at each end of the building helping to form the hip. These create point loads where the girder truss lands on the top plate. These point loads are carried by four extra 'critical studs' positioned in the wall below each girder truss. Where frames are joined at external corners, the framing forms a standard three-stud external corner, with no extra timber. Where frames are joined in the plane of a wall, one end will have a stud where a stud needs to be and the next panel will have an 'extra' stud enabling the panels to be fixed stud to stud.

3.1.3 Are nogs required or not, what size should they be?

According to NZS 3604, dwangs (nogs) are one way to supply lateral support and where required by *NZS 3604 clause 8.5.4 shall be spaced at not more than 1350mm centre-to-centre and shall not be less than 45mm x 45mm*. F&T has evolved to use full depth timber, as the use of small end section timber such as 45mm x 45mm is considered dangerous to nail in a factory setting. Full depth nogs have been used in all of the scenarios. Nogs are not required if sheathing is considered a direct fix external cladding complying with E2/AS1.

E2/AS1 mid frame nog

Where studs are greater than 450mm centres and there is no external sheathing, E2/AS1 9.1.8.5 requires an intermediate batten or other restraint to stop the insulation being pushed into the cavity. The intermediate batten or other restraint is supported by nogs. Initially, when cavity was introduced in 2005, E2/AS1 required those nogs to be at 800mm centres. This was changed to 1350mm centres in an amendment dated 2011. The change to 1350mm centres aligned E2/AS1 with NZS 3604; however, the amendment was not publicised so even now it may not be widely known and may be behind the industry preference for nogs at 800mm centres.

Soffit nog

E2/AS1 9.1.8.2 requires air movement to be restricted between a drained cavity and attic roof space. Cavity wall guidance published by MBIE explains closing off the top of the cavity is required to prevent damp air getting into interior spaces, roof framing and eaves. This is particularly important where the cavity finishes beneath a soffit or other area that might be open to a roof space. One way to close off the top of the cavity is to use a continuous length of horizontal batten as shown in Figure 11 below. It notes the horizontal batten also supports fixings at the top edge of sheet claddings where required. The diagram shows the horizontal batten is fixed to what is referred to as a 'soffit nog' in this report.

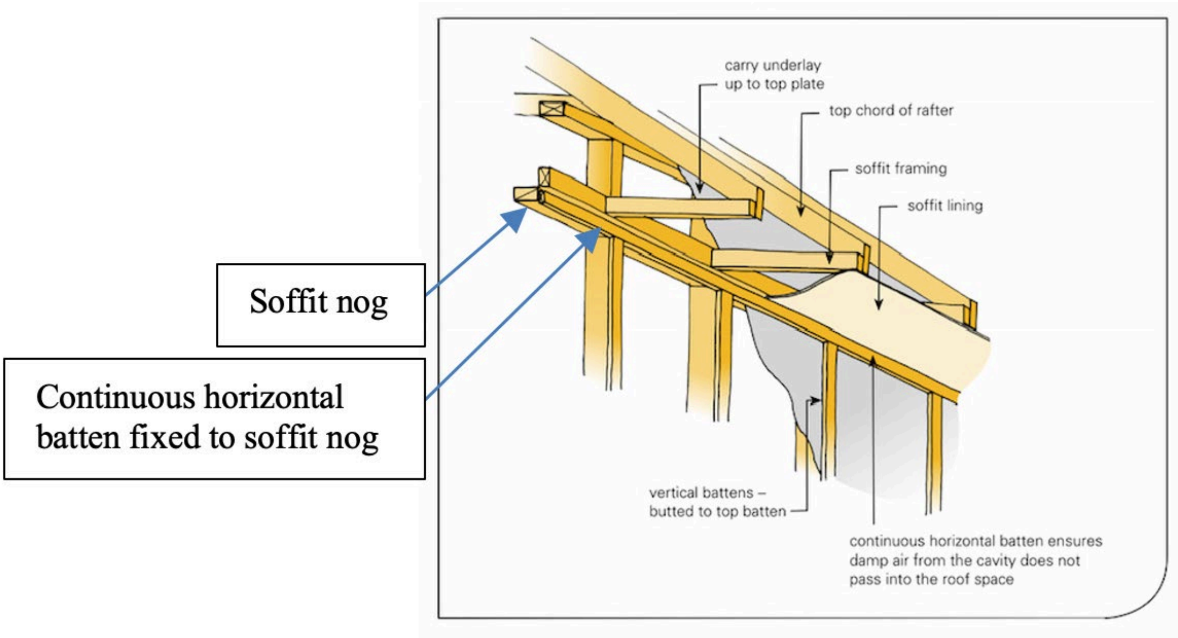


Figure 11: Illustration showing soffit nog 'closing off the top of the cavity' in MBIE's 'Constructing Cavities for Wall Claddings' document

3.1.4 Lack of awareness in industry

During the course of this work, researchers observed people working on the construction side of the industry who appeared to be generally unaware of insulation requirements (other than minimum R-values) and this indicates an area where education and upskilling may be beneficial. This lack of awareness may, in part, come from a paragraph inserted in the foreword of the current version of NZS 3604 stating it is intended NZS 3604:2011 will be referenced as an Acceptable Solution meeting the relevant performance requirements of both E3 and H1.

The Building Act requires all new building work to comply with the performance requirements of the NZBC. It is intended that NZS 3604:2011 will be referenced as an Acceptable Solution, meeting the relevant performance requirements of Clauses B1 'Structure' (for loads arising from gravity, earthquake, snow, wind and human impact, differential movement, non-structural elements and contents, and creep and shrinkage), B2 'Durability' (for timber and wood-based building components, steel fixings and fastenings, concrete foundations, concrete floor slabs, concrete masonry and reinforcing steel), E2 'External moisture', E3 'Internal moisture', and H1 'Energy efficiency'.

(an excerpt from NZS 3604:2011)

Even though NZS 3604 has standardised residential framing since 1978 and is cited as an Acceptable Solution, it appears that there has been little work to try to accurately assess the volume of timber in houses. From an insulation perspective, the percentages of framing are too high. Framing holding the building up, framing supporting claddings, and insulation all compete for space. If the volume of timber in buildings has to drop to levels that have a meaningful impact on wall R-values, this research shows it won't be a simple matter of applying some framing reduction choices currently available. It will require a concerted effort by industry and engineers to find the areas in NZS 3604 and E2/AS1 where reductions can be made or where the bridging effect of the framing can be mitigated. Given the challenges of reducing framing through design, a more workable solution may be to develop or adopt alternative framing systems such as those covered in Part Three of this report. It should also be noted that ensuring innovative insulation methods are compatible with NZS 3604 and E2/AS1 may also present challenges of their own.

4 Part One conclusions

Part One of this second stage of Beacon's Wall Project has been undertaken to gain insights into the range of drivers for higher-than-assumed wall framing content identified in Stage One. As a starting point, the research posed the following key question:

> ***Research Question 1: Which of the identified key drivers for high framing ratios are responsible for the largest amount of additional framing?***

This has been answered through analysis of a simple standard housing design tailored to explore drivers for different percentages of framing. Analysis shows that framing for structure (holding the house up) drives the higher-than-assumed rates of framing encountered in typical housing of the present day. Framing for structure also generally accommodates fixings for claddings with some small additions in the form of a soffit nog and other nog lines depending on the cladding.

A range of variables has been explored and, as the research shows, it is more a case of 'death by a thousand cuts' with each variable over and above baseline structural requirements (stud set-out for wind loading and, cladding specifications) contributing small percentages of timber on top of others. This is further complicated by a range of industry norms in which default settings routinely lead to slightly higher percentages of framing (e.g., an extra row of nogs) – though often for good reason (e.g., providing more rigid framing for handling on site or the default to cavity construction to improve weathertightness).

Importantly, analysis of current detailing techniques suggests that there is little in the way of unnecessary timber being added to framing. The bulk of the 90 x 45mm timber in the frame and the resulting wall is there for reasons relating to structure and weathertightness. The bulk of the framing is required by NZS 3604 which is cited as a means of compliance for NZBC clause, B1 Structure. In some cases, there is framing added which is extra to NZS 3604, mostly in the form of nog lines which are added to fix claddings to comply with E2/AS1 or support the cavity batten closer using the method described in MBIE guidance documents (see above). From a structural and weathertightness point of view the framing is necessary and not excessive.

What can be noted is that, even for a simple stand-alone single storey house of modest proportions, the range of claddings and set-outs resulted in percentages of framing that are far in excess of the 14-18% framing assumed in H1/AS1 definitions and methodologies – and much more in line with the average percentages of framing identified in Stage One of the Wall Project which showed an average of 34% framing across the sample. As covered in the introduction to this report, it is noted that the 14-18% framing is derived from areas of typical 'clear wall' i.e., the methodology specifically allows for the exclusion of corner studs, extra partition wall studs and framing around windows. However, this research establishes a base line that is much more illustrative of actual framing percentages.

Research Question 2: Can framing design be optimised to reduce wall framing ratios and, subsequently, reduce the effects of thermal bridging*?*

Utilising the skills of one of New Zealand's most experienced frame and truss (F&T) detailers the research has explored optimisation of framing (within the current paradigm of delivering a 'typical' timber-framed dwelling using framing as per NZS 3604 and E2/AS1).

Even taking a relatively simple single storey house design, and utilising several expert workarounds, the final percentage of framing in an optimised scenario could not be reduced from the original 'basic' detailing to a level below a 25% percentage of framing. Indeed, even a scenario in which nogs and dwangs had been eliminated and with structural support provided by rigid sheathing, still resulted in a percentage of framing of around 27%. Indeed, despite the skills of an experienced detailer working to optimise framing, it was a significant challenge to get below a percentage of framing of 27% on this relatively simple single storey house design.

The research indicates that within the current confines of existing standards, building code clauses, specifications, and exploring a range of typical cladding types, wind zones, construction requirements etc; optimising the percentage of framing in standard 90mm walls will not lead to a sufficient enough decrease in framing content (and thermal bridging) to achieve the ***intention*** of NZ Building Code construction R-value minimums. This is further explored in Part Two of this research, Impacts of framing, weak points and blind spots.

Part Two

Impacts of framing, weak points and blind spots

Part Two: Impacts of high framing content, weak points and blind spots

In addition to the high level of thermal bridging reducing the effectiveness of the thermal envelope, Beacon's original investigation[4] also highlighted significant weak points and blind spots in key aspects of current house construction. These 'thermal defects' include uninsulated corner junctions, uninsulated exterior perimeters of mid-floors, uninsulated interior to exterior wall junctions, and areas of timber for fixing flashings, timber packing and blocking. These further compromise the performance of the thermal envelope and are likely to lead to reductions in wall R-values and therefore, colder, less efficient houses, and an increased risk of condensation and surface mould in new housing. Part Two of the research utilised data gathered in the original wall project to assess and quantify the impact on wall construction R-values of the high percentages of framing encountered. It also assesses and quantifies the likely impact of the identified weak points/blind spots on the performance of the thermal envelope and, through modelling, deepened our understanding of the problem.

1 Method

Modelled construction R-values of external walls of new build houses (as-built, with weak points upgraded and with framing at 25%)

This study builds on the Stage One research reported in *Measuring the Extent of Thermal Bridging in External Timber-Framed Walls* (2020). In the **Stage One research**, the external walls of 47 houses under construction were measured[5] and their net percentage of timber framing calculated. The research also identified six weak points that were common amongst the walls of the 47 surveyed houses. These were:

1. Voids in external corners (no access to install bulk insulation)
2. Poorly insulated or voids in internal corners
3. Voids in internal to external wall junctions
4. No insulation over the top plate
5. No mid-floor perimeter insulation
6. No insulation on slab vertical edge

[4] *See Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2020). Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand. BRANZ external Research Report ER53 (Report Wall/3 from Beacon Pathway Inc.)*

[5] *Based on-site measurements and wall panel drawings from frame and truss companies.*

Where insulation was installed (or partially installed) at the time of the on-site survey, the R-value[6] and quality of installation was noted (i.e., general flaws, gaps etc.), as were other construction practices that would negatively impact the thermal performance of the wall. These included penetrations, blocking, excessive gaps where framing is poorly joined together and the use of plastic inserts under the bottom plate of the wall.

In Stage Two of the Wall Project, the aim of Part Two was to use data from five of the 47 houses surveyed in Stage One to calculate construction R-values of the external walls of each level and house, and determine the impact of resolving weak points and reducing framing percentages to 25%. The five sample houses are reasonably representative of the 47 houses in terms of size and materials, although their average framing percentage of 32% (26%-36%) is slightly lower than the houses surveyed (34%). They are relatively uncomplicated houses in terms of their configuration and widely available materials used.

The five sample houses selected were:

- 3 x single storey houses in Auckland, Wellington and Christchurch
- 2 x two storey houses in Auckland
- Total number of panels: 89
- Total number of levels: 7
- Wall Framing Percent: 26%, 31%, 32%, 32%, 35% (framing from the first level in each house), 29%, 36% (framing from the second storey level of the two double storey houses)
- Floor area: range from 110 - 145m^2

Initially, the wall construction R-values were calculated for each of the five properties with R2.0, R2.2 and R2.8 insulation. The calculations assumed insulation was perfectly fitted which was not the case from field observations during the initial data collection of Stage One. In addition, the five sample houses have an average percentage of framing of 32%, whereas average percentage of framing of the 47 surveyed houses was 34%. As such, the calculated wall construction R-values presented in this study are **conservative** and may over-state the actual thermal resistance of the walls[7].

This was followed by a series of modelling treatments to quantify the impact of the weak points on R-values for the as-built wall panels and then again using a reduced framing content of 25%, which was considered a realistic percentage to aim for in an optimised framing scenario[8].

***
[6] R2.0 and R2.2 were noted on site or on drawings most commonly. R2.4 was noted occasionally.

[7] The magnitude of heat loss from poorly installed insulation is not factored into our calculations nor our modelling as research on this question remains unsatisfactorily researched in New Zealand.

[8] In Stage 1 of this research, the average wall framing percentage amongst the 47 surveyed dwellings was found to be 34%, ranging from approximately 20-50%. Modelling at 25% framing was selected as it was considered to be a level the frame and truss industry could potentially achieve, albeit with some challenges.

In summary, three sets of calculations or modelling treatments were undertaken on each of the sample properties.

Treatment 1: Base case (S1) - As-built - modelled for R2.0. R2.2 and R2.8 insulation

Treatment 2: Weak points upgraded (1Up, 5Up, and 6Up with the suffix of 'Up' denoting an upgrade) - modelled for R2.0. R2.2 and R2.8

Treatment 3: Reduced framing (25%) – applied to Treatment 1 and 2

Note regarding terminology:

- 1Up refers to modelling the effect of insulating the concrete floor slab vertical edge only (commonly referred to as 'perimeter slab insulation'.
- 5Up refers to the five other common weak points (excluding the floor slab edge). Because the effect of each of these weak points individually is relatively small, they are assessed together, as a group of weak points.
- 6Up combines 1Up and 5Up, such that the effect of upgrading all six weak points is modelled.

These treatments are explained in more detail below.

1.1.1 Treatment 1: Base case (as-built) wall construction R-values for each level and house were calculated using the following method

Step 1. An Excel Wall Panel Spreadsheet was set up for each of the five sample houses, with a tab for each individual wall panel (see Figure 12 below, with example)**.**

WALL PANEL SPREADSHEET

Panel	PF/E3
Length m	2.64
Height m	2.42
Gross Area m^2	6.38
Opening Area m^2	1.84
Opening Perimeter m	5.66
Net Area m^2	4.53

Framing Content (as surveyed)	46.19%
Framing Content (adjusted for PSI Values	26.37%
Mid-depth timber and voids	1.12%

Primary Panel U-value W/(m^2K)	0.591
Primary Panel R-value (m^2 K)/W	1.692

Insulation	R2.2
ISO Calculated U-Value (timber with a PSI-value applied is excluded)	0.591

Component / Weak-Point		U-Value W/(m^2K)	Area (m^2)	PSI Value W/(m.K) (Uninsulated, as surveyed)	Length (m)	Number	Heat Loss (W/K)
Primary Panel (timber PSI adjusted)		0.591	4.53				**2.68**
Weak points	External Corner			0.020	2.42	1	0.048
	Internal Corner			0.184	2.42	0	0.000
	Internal Wall Junction			0.152	2.42	0	0.000
	Floor Plate on Slab			0.273	2.64	1	0.721
	Top Plate			0.036	2.64	1	0.095
	Mid Floor			0.155	2.64	0	0.000
	Window or door			0.040	5.66	1	0.226
				Sub-Total			**1.09**
					TOTAL Panel Heat Loss (W/K)		**3.77**

Figure 12: Individual panel spreadsheet tab (wall panel spreadsheet)

Step 2. Wall panel R-values are calculated in two parts. As can be seen in Figure 12 above, the aim is to determine the Total Panel Heat Loss (W/K). To do this, we firstly have to determine heat loss from: a) the Primary Panel (includes timber and insulation) and b) the timber associated with a corner, junction or opening.

In the first part[9], the primary pieces of timber (i.e., those not associated with corners, openings or junctions) are measured and their percentage of framing calculated. Based on this percentage of framing and the level of insulation, the wall panel's U-value is calculated using the ISO U-value calculator (see below). The U-value is then multiplied by the panel area resulting in a heat loss factor (W/K) for the panel (see the blue highlighted row in Figure 12 above).

The second part[10] involves adding heat loss or gain (W/K) from the pieces of timber associated with a corner, opening or junction. This is achieved by multiplying the PSI-value for the specific junctions[11] (weak-point) by their linear length (see the yellow highlighted row in the table above). The resulting heat loss sub-total (W/K) is added to produce a TOTAL Panel Heat Loss. This is then converted into a U-value (by dividing the TOTAL Panel Heat Loss by the panel area) and an R-value (1/U-value).

Step 3. Each individual wall panel was initially assessed to identify which pieces of timber framing to exclude from the Primary Panel Timber framing percentage and U-value calculations. Heat loss from the excluded pieces of timber framing is accounted for in separate junction PSI-value calculations. The example in Figure 13 shows the pieces of timber (in red) whose area is excluded from Primary Panel framing percentage and U-value calculations. These are excluded because they are accounted for in the separate PSI-value heat loss calculations. The pieces of framing excluded are made up of the area of the top and bottom plate timber, the area of timber around openings, corners, and the internal wall junctions. Where the left or right edge of the panel is not a corner, the timber is not excluded. If an internal wall junction occurs (not present in this example), timber connected to the junction is also excluded. For each wall panel, the gross panel area, timber framing area, timber framing percentage (adjusted for PSI values) and opening area were entered into the Wall Panel Spreadsheet. Weak points were also noted. This data was sourced from Beacon Pathway's Stage One Report, *Measuring the Extent of Thermal Bridging in External Timber-Framed Walls*.

[9] Blue highlighted row of table above

[10] Yellow highlighted cells in table above

[11] A table of the PSI-values used in this research is below.

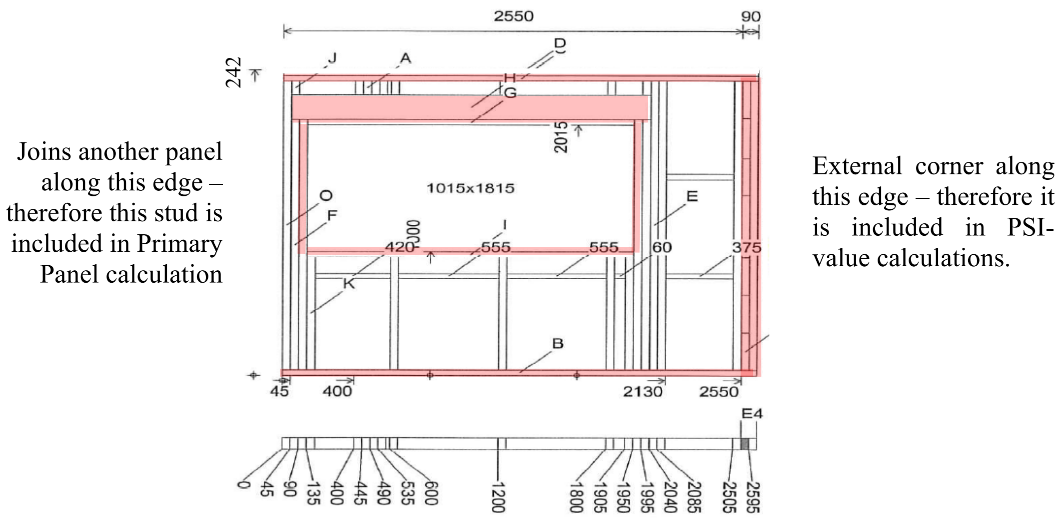


Figure 13: Framing timber excluded from Primary Panel framing percentage calculations

Step 4. The Primary Panel U-value was determined by inputting the area ratio percentages for each material that made up the wall framing (adjusted for PSI-Values) and mid-blocks, insulation and air voids into the ISO calculator[12], along with the conductivity and thickness of each (Figure 14 below).

The conductivities used for constants such as 90mm wide timber (2 x 45mm), 45mm timber, 45mm air gap and 10mm plasterboard are: 0.13, 0.24 and 0.22 (W/mK) respectively. In this example the conductivity of R2.2 insulation is 0.041 (W/mK). The conductivity of R2.0 insulation is 0.045 (W/mK), and 0.032 (W/mK) for R2.8 insulation.

[12] *Passive House Australia New Zealand ISO 6946 U-value calculator*

Component Nr.	Component Label

Internal Surface Resistance R_{si}: 0.13 m²K/W

	Range 1	Range 2	Range 3	Thickness d in mm	Thermal Conductivity λ in W/(mK) Range 1	Range 2	Range 3
1.	Insulation	Timber	block	45	0.041	0.130	0.130
2.	Insulation	timber	air	45	0.041	0.130	0.240
3.	plasterboard			10	0.220		
4.							
5.							
6.							
7.							
8.							
9.							

Thickness of Component: 100 mm

Thermal Resistance of Unheated Space (e.g. Roof Space) R_u:

Area Ratio: 72% | 26.0% | 2.0%

External Surface Resistance R_{se}: 0.13 m²K/W

Figure 14: ISO-Calculator table used to determine each wall panel's U-value (Primary Panel)

Step 5. This results in the generation of an R-value and U-value for each panel. For the example provided above with 72% R2.2 insulation, 26.0% framing and 2.0% mid-depth blocking, these are:

$R_{T(0)}$-Value: 1.692 m²K/W **U-Value: 0.591 W/(m² K)**

The U-value (0.591 W/m^{2}K) is entered into the blue highlighted row of the Individual Panel Spreadsheet Tab (Figure 12 above). U-values are converted to R-values at a later stage when determining the whole of house wall R-value. For the first scenario, R2.0 insulation was modelled. For later scenarios exploring the same panel, insulation measuring R2.2 and then R2.8 were modelled.

Step 6. PSI-values for the weak points relevant to each wall panel were entered into the Individual Panel Spreadsheet Tab (Figure 12 above) and the heat loss for each weak-point present was calculated. The TOTAL Panel Heat Loss is calculated by adding the Primary Panel heat loss **(2.68 W/K)** with the heat loss due to weak points **(1.09 W/K)**. In the example above (Figure 12), the TOTAL Panel Heat Loss is **3.77 W/K**. The PSI-values for un-insulated and insulated junctions/weak points are shown in Table 2 below. These were sourced from BRANZ[13]. PSI-values for un-insulated junctions were used in U-value calculations of walls as surveyed on site (i.e., Treatment 1; Base case S1), whereas the PSI-values for insulated junctions[14] were used for modelling weak point upgrades 1Up, 5Up and 6Up.

[13] ***BRANZ (2021) ER61. High Thermal Performance Construction Details Manual - UNPUBLISHED***

[14] ***For example, voids in corners and internal wall junctions were filled with insulation, or top-plate was covered with insulation.***

Table 2: PSI-values used in modelling weak points

<table>
<tr><th>Wall Junction PSI Values
(90mm timber framing)</th><th>Un-Insulated Weak Points
(as surveyed)
(W/mK)</th><th>Insulated Weak Points (Upgraded)
(as modelled)
(W/mK)</th><th colspan="2">Modelling Upgrades</th></tr>
<tr><td>External Corner</td><td>0.020</td><td>-0.019</td><td rowspan="5">Used together as ‘5Up’</td><td rowspan="6">Used together as ‘6Up’</td></tr>
<tr><td>Internal Corner</td><td>0.184</td><td>0.047</td></tr>
<tr><td>Internal Wall Junction</td><td>0.152</td><td>0.180</td></tr>
<tr><td>Top Plate</td><td>0.036</td><td>-0.042</td></tr>
<tr><td>Midfloor Perimeter
(2 level houses only)</td><td>0.155</td><td>0.075</td></tr>
<tr><td>Floor Slab
(perimeter vertical edge)</td><td>0.273</td><td>-0.268</td><td>Separated as ‘1Up’</td></tr>
<tr><td>Doors</td><td>0.040</td><td>0.040</td><td colspan="2" rowspan="2">These PSI-values were estimated based on BRANZ (2021)[8]</td></tr>
<tr><td>Windows</td><td>0.100</td><td>0.100</td></tr>
</table>

(Source: BRANZ 2021/Quinn Unpublished)

Step 7. The as-built performance U-Value for each individual wall panel is then calculated by dividing the TOTAL Panel Heat Loss by the net panel area. In the example above, this is **3.77 (W/K)/4.53m^2 = 0.832 W/m^{2}K**. This number automatically populates the Master Tab (see highlighted row of Table 3 below) which is included in the Excel **Wall Panel Spreadsheet**

Step 8. Once U-values for all individual wall panels are calculated and added to the Master sheet, they are then converted to R-values (= 1/U-value = 1/0.832 = 1.201). The total R-value (i.e., the construction wall R-value for each level) is then calculated based on the area weighted value of all panels, as shown in this formula:

$$\text{R-value}_{Level} = \frac{1}{[\ (\%area/R)_{E1} + (\%area/R)_{E2} + (\%area/R)_{E3+} \ldots\ldots (\%area/R)_{En}]}$$

For single storey houses, this **is** the as-built (construction) wall R-value for the house. For two storey houses, the total as-built (construction) wall R-value for the whole house is calculated, also using the same method.

The resulting R-values for each level or house are entered into the Full Primary Results Table (see Appendix One: Modelling results summaries).

Table 3: Example of Master tab for each house level

Master Tab – Wall Panel Spreadsheet (Whole Level or House)						
Panel	Final Panel U-value	Final Panel R-value	Net Area of Panel m^2	Panel Percentage of Wall area for the Level (Based on Net Wall Area)	**Panel-Level U Value**	
E1	0.668	1.496	9.03	0.137	0.0919	
E2	0.731	1.368	8.30	0.126	0.0923	
E3	0.832	1.201	4.53	0.069	0.0574	Example
E4	0.742	1.347	3.88	0.059	0.0438	
E5	0.793	1.261	2.41	0.037	0.0290	
E6	0.722	1.385	2.63	0.040	0.0289	
E7	0.822	1.217	3.48	0.053	0.0435	
E8	0.653	1.531	14.42	0.219	0.1433	
E9	0.685	1.459	10.55	0.161	0.1101	
E10	1.027	0.973	6.48	0.099	0.1014	
					0.742	**Total Wall U-value Level**
					1.347	**Total Wall R-value Level**

1.1.2 Treatment 2 and 3: Modelling the impact of weak points and reducing framing percentage on R-values for each level and house.

The same methods and calculations as described above were used to determine the impact of the weak points and to model the result of reducing the percentage of framing to 25% (considered an appropriate framing percentage to aim for with an optimised approach[15]). The difference is that the PSI values used in the initial calculations (for the as-surveyed**, un**insulated junctions) were replaced with PSI values for insulated junctions, and grouped as upgrades 1Up, 5Up and 6Up[16] for the modelling (as shown in PSI-value table, Table 3 above). Given that most panels did not have all the weak points, especially corners, internal wall junctions and mid-floors, it made sense to group them according to their relative occurrence.

The difference in PSI-value between an uninsulated floor slab and an insulated floor vertical slab edge was by far the largest difference of any of the weak points at 541 W/(m.K) (i.e., from a heat loss of 0.273 W/(m.K) to a heat gain effect of -0.268 W/(m.K)) and sufficiently large to warrant it being modelled on its own as '1Up'.

[15] This is also informed by Part 1 of this current Wall Project Research which explored optimised framing scenarios with an expert detailer from the frame and truss industry

[16] The 'Up' stands for 'upgrade' which refers to the situation where previously uninsulated junctions are insulated (i.e., upgraded)

Once the modelling for the impacts of weak points was completed (i.e., modelling the effect of insulating or upgrading the weak points), modelling for a framing content of 25% was undertaken. This was achieved by using the ISO calculator to re-calculate the Primary Panel U-value for each wall panel using 25% as the framing area ratio. This new panel U-value was added to the Individual Panel Spreadsheet Tab (Figure 12) with the existing data for Treatment 1 (as surveyed) and Treatment 2 (applying the PSI-values for weak point upgrades) and a new heat loss factor, U-value and R-value were calculated for each panel. And, as previously described, the R-value for each level and house with a maximum of 25% framing was then calculated based on the area-weighted value of each panel.

2 Results

Three sets of primary results are presented in this section along with a number of secondary results, that, while outside of the scope of the original research, provide valuable insights on this topic.

Wall system R-values of surveyed houses (S1): A sample of five of the 47 houses surveyed as part of Beacon's original study[17] were selected and their wall construction R-values calculated. These R-values are shown under column(s) 'Base case S1' in Table 4 below. They are illustrative of the thermal performance of walls of new build houses, which typically have framing percentages around 35% and contain up to 6 different weak points (e.g., uninsulated junctions). The wall system R-values are calculated for R2.0, R2.2 and R2.8 insulation. Note: 'S1' denotes '*As-Surveyed'* (or *As-Built*).

Wall system R-values with weak points resolved (1Up, 5Up and 6Up): Using the same five sample houses, wall R-values are calculated with weak points resolved. Six main weak points were identified in the previous study. Typically, these are junctions where insulation has not been installed and include external corners, internal corners, internal wall junctions, above the top plate, the midfloor perimeter on two-level houses and, the edge of the floor slab. Heat loss from these areas can be significant. In this set of results, wall system R-values for the five sample houses are modelled with R2.0, R2.2 and R2.8 insulation, assuming the weak points are insulated.

Columns labelled 1Up, 5Up and 6Up on Table 4 below show these results for the different insulation levels modelled (R2.0, R2.2, R2.8).

Note:

- 1Up refers to modelling the effect of insulating the concrete floor slab vertical edge only (commonly referred to as 'perimeter slab insulation'.

[17] ***Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2019). Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand. Final Report – Building Levy Project LR11092. Report Wall/3 from Beacon Pathway Inc.***

- 5Up refers to the 5 other common weak points (excluding the floor slab edge). Because the effect of each of these weak points individually is relatively small, they are assessed together, as a group of weak points.
- 6Up combines 1Up and 5Up, such that the effect of upgrading all 6 weak points is modelled.

Most individual wall panels do not have all 6 weak points present. For example, only some panels have corners or internal wall junctions or a midfloor. Because single level properties do not have a midfloor, this particular weak point is excluded from the upgrade modelling for the three 1-level sample properties. However, from a whole house perspective, all six weak points were present in the wall system of the two two-level sample properties.

Wall System R-values with a maximum of 25% timber framing: One of the key aspects of the research was to explore the potential effect on wall R-values by reducing framing percentages. Using the same data as used in the 2 sets of results described above, wall construction R-values of the 5 sample buildings are modelled with a framing content of 25% of the net wall area. The resulting wall R-values are shown on Table 4 below (i.e., modelled at a percentage of framing of 25% of the net wall area).

The surveyed framing percentages for the five sample properties (i.e., seven levels) ranged from 26-36%. Hence, we can see what the impact of reducing the framing to 25% will be on wall R-values. For the sample wall systems with surveyed framing percentages around 35%, modelling framing at 25%, constitutes a **30% relative reduction in framing content**, which is significant. For the sample property surveyed with 26% framing, a reduction in framing from 26% to 25% constitutes a 4% relative reduction in framing content.

Headline results are presented below - please see Appendix One: Modelling results summaries for full table of results.

2.1.1 Primary results

Summary: Table 4 below shows the primary results[18] of the base case, upgrades, and upgrades with reduced framing percentages together. The **Base case S1** column shows the whole house wall system R-values averaged (with ranges) for the five sample houses[19] at their as-built framing percentages (26-36%), with R2.0, R2.2 and R2.8 insulation installed.

The next three columns show the modelled, whole house wall system R-values averaged (with ranges) for the five sample houses with **Upgrades 1Up, 5Up and 6Up**, with as-built (as-surveyed) framing percentages (26-36%) and R2.0, R2.2 and R2.8 insulation installed.

The remaining four columns show the same set of results when modelled with **25% framing**.

[18] *See Appendix One for full table of results.*

[19] *House 1, 2 and 3 are single level houses with floor areas 110, 145 and 144m^2 and 32%, 26% and 35% framing respectively. Houses 4 and 5 are two-level with floor areas of 115 m^2 and 141 m^2. Framing is 31% (L1) 29% (L2) for house 4 and 32%(L1) and 36%(L2) for house 5.*

As the table indicates, the R-values are higher with a higher level of insulation installed and with lower framing percentages[2].

With upgrade 1Up (slab edge insulation) and R2.8 insulation installed, whole house wall system R-values approach or exceed R2.0 (which is a minimum level for current H1/AS1 schedule method R-values of R1.9 / R2.0 for walls depending on climate zone). With upgrade 5Up, R-values do not exceed R1.90, even with R2.8 insulation installed and 25% framing. With all six upgrades, average wall R-values with as-built framing percentages exceed R1.90, achieving R2.35 (2.00-2.69) with R2.8 insulation.

Table 4: Primary results: Wall construction R-values (averaged across five sample houses, with ranges)

Insulation Level	Modelled with *as-built* framing percentages (26-36%)				Modelled at 25% Framing			
	BASECASE S1 As-Built (with Weak points)	**1UP** 1 Weakpoint Resolved	**5Up** 5 Weak points Resolved	**6Up** All 6 weak points Resolved	**S1** + 25% Framing (with weak points)	**1UP** +25% Framing +1 Weakpoint Resolved	**5Up** +25% Framing +5 Weak points Resolved	**6Up** +25% Framing All 6 Weak points Resolved
R2.0	**1.26** (1.21-1.32)	**1.70** (1.47-1.90)	**1.39** (1.30-1.47)	**1.95** (1.69 -2.18)	**1.33** (1.27-1.38)	**1.84** (1.58-2.14)	**1.48** (1.43-1.53)	**2.15** (1.85-2.47)
R2.2	**1.30** (1.24-1.38)	**1.81** (1.53-2.10)	**1.44** (1.34-1.59)	**2.06** (1.77-2.32)	**1.38** (1.32-1.41)	**1.97** (1.65-2.26)	**1.55** (1.49-1.61)	**2.29** (1.94-2.68)
R2.8	**1.40** (1.31-1.49)	**2.02** (1.69-2.38)	**1.57** (1.47-1.68)	**2.35** (2.00-2.69)	**1.53** (1.42-1.59)	**2.30** (1.88-2.67)	**1.73** (1.62-1.82)	**2.74** (2.29-3.27)

2.1.2 Primary results details

2.1.2.1 Primary results 1: Wall system R-values of surveyed houses (S1)

Table 4 above shows whole-of-house wall R-values averaged across the five sample houses. (Also see Appendix One: Modelling results summaries for full table of results.

For the **Base case (S1)** with R2.0 insulation, R-values range from R1.21- R1.32; with R2.2 insulation, R1.24- R1.38 and with R2.8 insulation R1.31- R1.49. Of note is that, even with R2.8 insulation installed, wall construction R-values for all sample houses are still well below R1.9 and only approaching R1.5 in one case, with R1.49 where the sample house had a lower than typical percentage of framing of just 26%.

Analysis of Primary results 1

These results indicate that the overall thermal resistance of external walls (as-built) is well below recommended levels and likely to present as a pathway for excessive heat loss (i.e., inefficient and/or ineffective heating) and therefore present a condensation and mould risk, especially if the ceiling and underfloor are comparatively well-insulated.

2.1.2.2 Primary results 2: Wall system R-values with weak points resolved (1Up, 5Up and 6Up):

Upgrade 1Up (slab edge insulated) increases the average whole house wall construction R-values to R1.7(R2.0), R1.81(2.2) and R2.02(R2.8), a **35% - 44% increase**[20] in wall R-value compared with the Base case (S1: R2.0, R2.2 and R2.8) with slab edge <u>un</u>insulated (see Figure 15 below). With the slab edge insulated and R2.8 insulation installed, whole house wall R-values for the single level houses exceed R2.0 even with as-built framing percentages in the mid-thirties[21].

With **upgrade 5Up** (five weak points insulated) and as-built framing percentages (S1), whole house wall R-values are between R1.39 (R2.0), R1.44 (R2.2) and R1.57 (R2.8). This is a **10-12% increase** in wall R-values compared to the Base case (see Figure 15 below), 25-30% less than that achieved by upgrade 1Up (slab edge insulated).

Upgrade 6Up is when all the weak points are insulated. At as-built framing percentages, modelling shows that upgrade 6Up achieves average whole house wall R-values ranging from R1.95 (R2.0), R2.06 (R2.2) and R2.35 (R2.8), a **55-68%**[22] increase compared to the Baseline cases with as-built framing percentages.

Analysis of Primary results 2

These results reveal that upgrading weak points can have a significant positive impact on whole-of-house wall system R-value. The size of the impact is related to the number and type of weak points present, i.e., not all wall panels have all the weak points and some houses have more than others depending on the design (e.g., the number of internal and external corners, and/or internal wall junctions – see Part One: Exploring drivers of current percentages of framing for a greater understanding of these issues).

The largest single increase in R-value is due to the floor slab edge being insulated **(1Up).** Insulating the floor slab edge (1Up) <u>on single level houses</u> improves the whole house wall system R-value by around **40%** (35-44%) when compared with the as-surveyed R-value **(S1)** – e.g., from approx. R1.40 to R2.02

[20] For single level houses the increase is 45-57%; for two level houses the increase is 19-21%
[21] See Appendix One: Modelling Results Summaries
[22] For single level houses the increase is 67-100%; for two level houses the increase is 36-46%

for R2.8 insulation. On two-level houses, when 1Up is calculated across the whole house (i.e., both levels), the average wall system R-value increase is only 20% because the gains in R-value from 1Up are restricted to the ground level. Insulating the edge and beneath the second level walls (which sit on suspended wooden floors) achieves a small R-value increase (<5%) in comparison.

Insulating the floor slab edge (1Up) on single level houses improves the whole house wall system R-value by **32%$_{\mathbf{ave}}$** (i.e., from R1.54 to R2.04), which is more than upgrade 5Up which deals with five weak points simultaneously. Similar improvements, of course, can be achieved for the ground floor of 2-Level properties. However, when calculated across both levels, the average wall system R-value is only 5% higher than 5Up.

When all 6 upgrades are implemented **(6Up)**, the increase in averaged whole house wall system R-value for the five sample properties is 55% (R2.0), 58% (R2.2) and 68% (R2.8). For single level properties (and the ground floor of two-level houses), the improvement is between 65-100% when compared with the Base case (S1). For two-level houses, the increase in wall R-value across the whole house is 36-46% in comparison to S1.

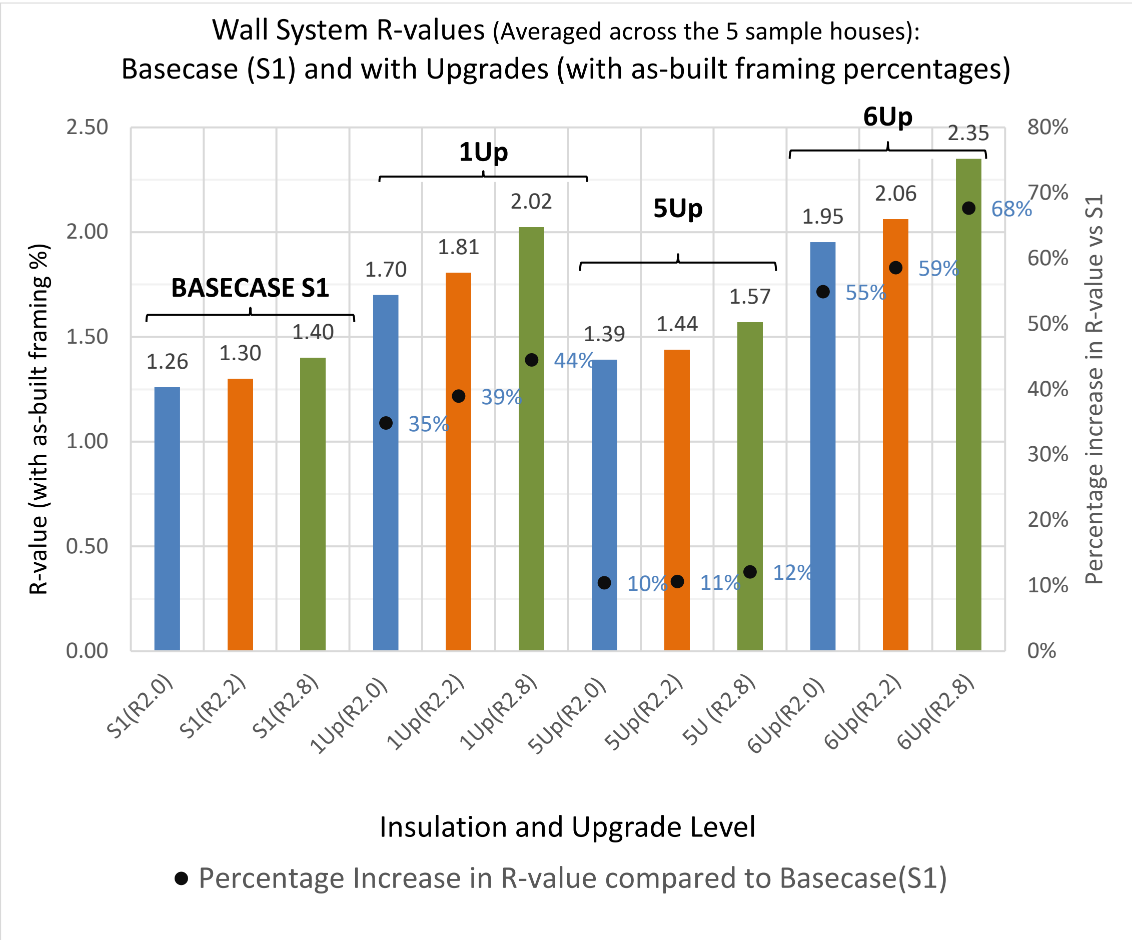


Figure 15: Wall system R-values (averaged across the five sample houses)

2.1.2.3 Primary results 3: Wall system R-values with a maximum of 25% timber framing:

As can be seen in Figure 16 below, with framing reduced to 25%, the average R-values for the **Base case (S1) increase by 6-8%.** For R2.0 insulation, this is an increase from R1.26 to R1.33. For R2.2 insulation, from R1.30 to R1.38, and for R2.8 insulation, R1.41 to R1.53.

With **upgrade 1Up** and framing percentages reduced to 25%, wall R-values **increase by 8-13%** when compared to 1Up with as-built framing percentages. This is a 38-51% increase in wall R-value compared with the Base case(S1) with 25% framing (e.g., R1.84 (1Up-R2.0) compared to R1.33 (S1-R2.0)). When compared to the Base case(S1) with as-built framing percentages, the increase is 46-64%. With the slab edge insulated and framing percentage at 25%, wall construction R-values of single level houses with R2.2 insulation installed exceed R2.0[23]. With R2.8 insulation installed, walls achieve around R2.5[1].

With **upgrade 5Up** and framing percentage at 25%, wall R-values increase to R1.48, R1.55 and R1.73 respectively for the different insulation levels, a 7-10% increase compared to upgrade 5Up with original framing percentages. When compared to the Base case (S1) with 25% framing, the increase is marginally higher at 12-14%. When compared to the Base case (S1) with as-built framing percentages, the increase is 18-23%.

With **Upgrade 6Up** and framing reduced to 25%, the increase in average wall R-values is 10-17% depending on the insulation level. This is a 61-80% increase compared to the Base case S1 (at 25% framing). When compared to the Baseline case with the as-built framing percentages, the increase is 89-134%.

[23] ***The 2 x 2 level houses bring the average down to R1.97 (for R2.2 insulation) and down to R2.30 (for R2.8 insulation).***

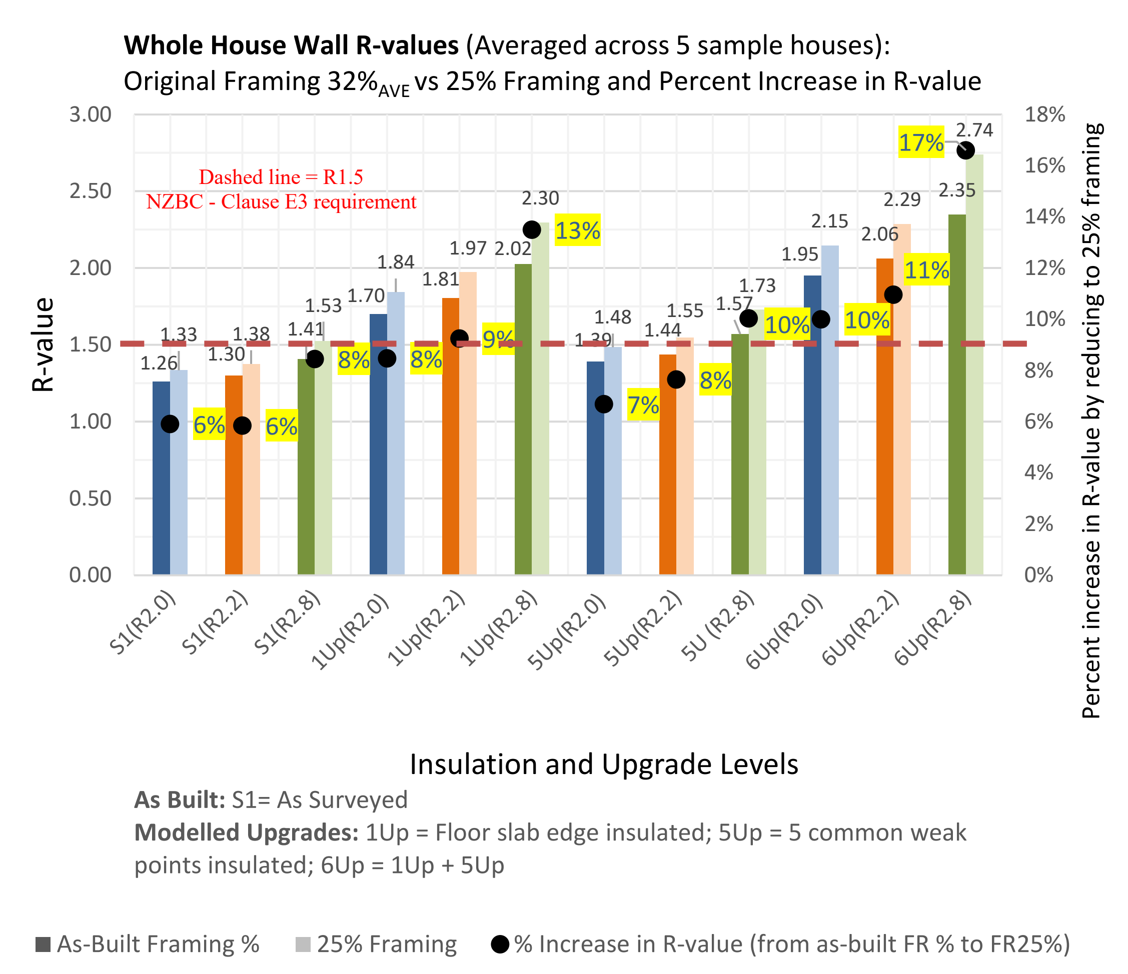


Figure 16: Whole house wall R-values (Averaged across five sample houses)

Analysis of primary results 3

As can be seen by Figure 16 above, limiting wall framing to 25% (from an average of 34%) will have a positive impact on wall system R-value. The positive effect increases with the level of insulation and the level of weak point upgrade. For the as-surveyed wall panels (S1), reducing framing to 25% will see wall R-value increase by 6-8%. This is still well below NZ Building Code Clause H1/AS1 requirements and only just achieves NZBC Clause E3/AS1 (minimum R1.50) with R2.8 insulation. R-value increases due to limiting framing to 25% are greater (10 -17%) when weak points are resolved, especially when insulating the floor slab edge. Once again it should be noted that the modelling used in this approach is not directly comparable to the approach taken in H1/AS1 in relation to the definitions of construction R-values and the permitted exclusion of certain framing members (see introduction of this report and specifically **Framing and thermal bridging definitions – an explanatory note**).

Based on Beacon's earlier research, the average amount of timber framing in prefabricated wall panels is around 34%, ranging from around 20-50%. Therefore, most wall panels as currently fabricated would have to be significantly redesigned to achieve a framing percentage of 25% of net wall area. That means wall panels would need to lose around 30% of the timber they are currently designed with. While optimisation of wall framing (and aiming for lower percentages of thermal bridging) should be a priority, that, in itself, is unlikely to result in sufficiently large reductions, as wall panel designers and manufacturers have reported that they already try to minimise the amount of framing in wall panels (refer to parallel research carried out with the frame and truss industry and reported on in Part One: Exploring drivers of current percentages of framing).

Meaningful reductions in wall framing percentages would require significant redesign and potentially a range of solutions that sit outside current structural requirements of NZS3604 and other industry requirements (e.g., specifications for fixings for cladding and linings etc.).

Given the challenges involved in reducing framing percentages, and the relatively small R-value gains available from reduced framing ratios, aiming for a reduction in framing on its own is a limited strategy. If there is a desire to achieve wall construction R-values greater than R2.0 (which is, internationally, a low target), yet retain current design, manufacture and construction of walls, then a number of principles should be followed. These include:

1. Always specify minimum R2.8 bulk insulation (in 90mm wall construction)
2. Ensure the vertical slab edge is properly insulated and remains so for the life of the house
3. Optimise framing: through enhanced design, engineering and expert detailing, reduce the percentage of framing and thermal bridging by all means possible without compromising structural or weathertightness requirements
4. Minimise complexity in the wall configurations (to eliminate internal and external corners)
5. Minimise the number and size of openings and try to place them in large panels
6. Declare nominal framing percentages on panel production drawings and associated documents.

However, applying all these principles consistently across the design, fabrication and installation of wall panels is unlikely to occur due to the many factors involved. Furthermore, thermal bridging through the timber framing is still ultimately not addressed by this approach and will continue to be a source of heat loss and potential location of condensation and mould.

An alternative approach, and one that will resolve many of the issues highlighted above, is to install an additional thermal layer on the inside or outside of the existing wall system. This creates a thermal break between the timber framing and the external environment as well as providing space to increase insulation thickness by 50% to approximately 140mm (from 90mm). Examples of a range of these solutions are explored in Part Three: Advanced framing and insulation solutions.

2.1.3 Secondary results

Data collected in Stage One of the Wall Project research[1] has allowed additional analysis to be undertaken. In this section, three secondary results are presented that add to our understanding of thermal bridging and heat loss through typical timber-framed walls of residential buildings.

2.1.3.1 Relationship between framing percentage and wall panel R-value

Figure 18 (below) shows the relationship between the percentage of framing and wall panel R-value for different levels of insulation. As can be seen, there is often a spread of R-values for the same percentage of framing. This is due to a range of factors including the number and type of weak points present in the particular panels. The trendlines tend to mitigate the effect of this variation.

While it is clear is that R2.8 insulation provides the highest construction R-values and R2.0 the lowest, the difference between them is not large, especially at higher framing percentages. For example, moving from an insulation value of R2.0 to R2.8 at 40% framing sees construction R-value move from R1.15-R1.27, an increase of R0.12, around 10%. At 25% framing, the increase is from 1.47 to R1.70, an increase of R0.23 or 16%. These examples are shown as blue (R2.0) and green (R2.8) diamonds on Figure 18 (below).

2.1.3.2 Impact of openings

The graph below (Figure 17) shows how the addition of an opening in a wall panel affects the amount of timber framing within that panel. While the overall percentage of framing tends to reduce as panel size increases for both panels with and without openings, the trendlines indicate the difference in percentage of framing between the panel types increases. For example, adding an opening to a $4m^2$ panel increases the percentage of framing by approximately one third (i.e., from 30% to 40+%), as indicated by arrow 1 (black) below. Adding an opening to a $12m^2$ panel doubles the percentage of framing (from around 17.5% - 35%), arrow 2 (red) below.

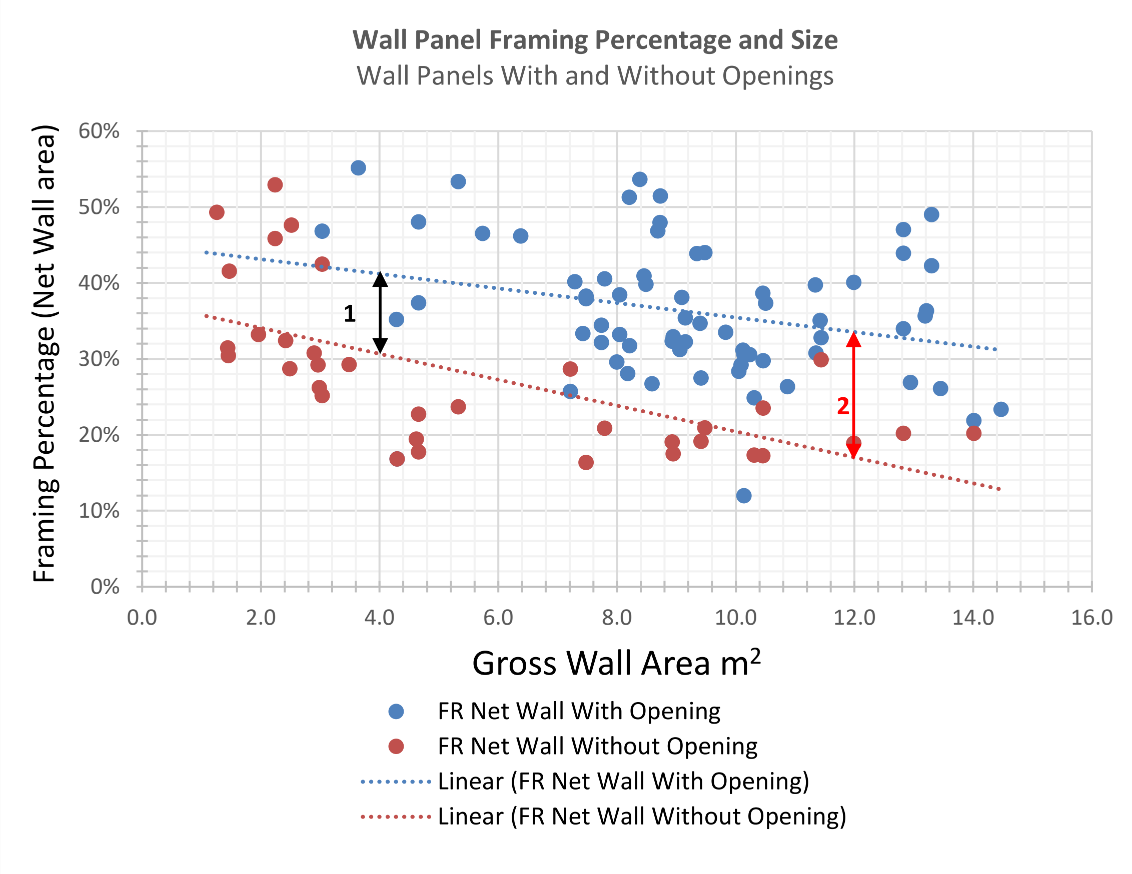


Figure 17: Wall panel framing percentage and size

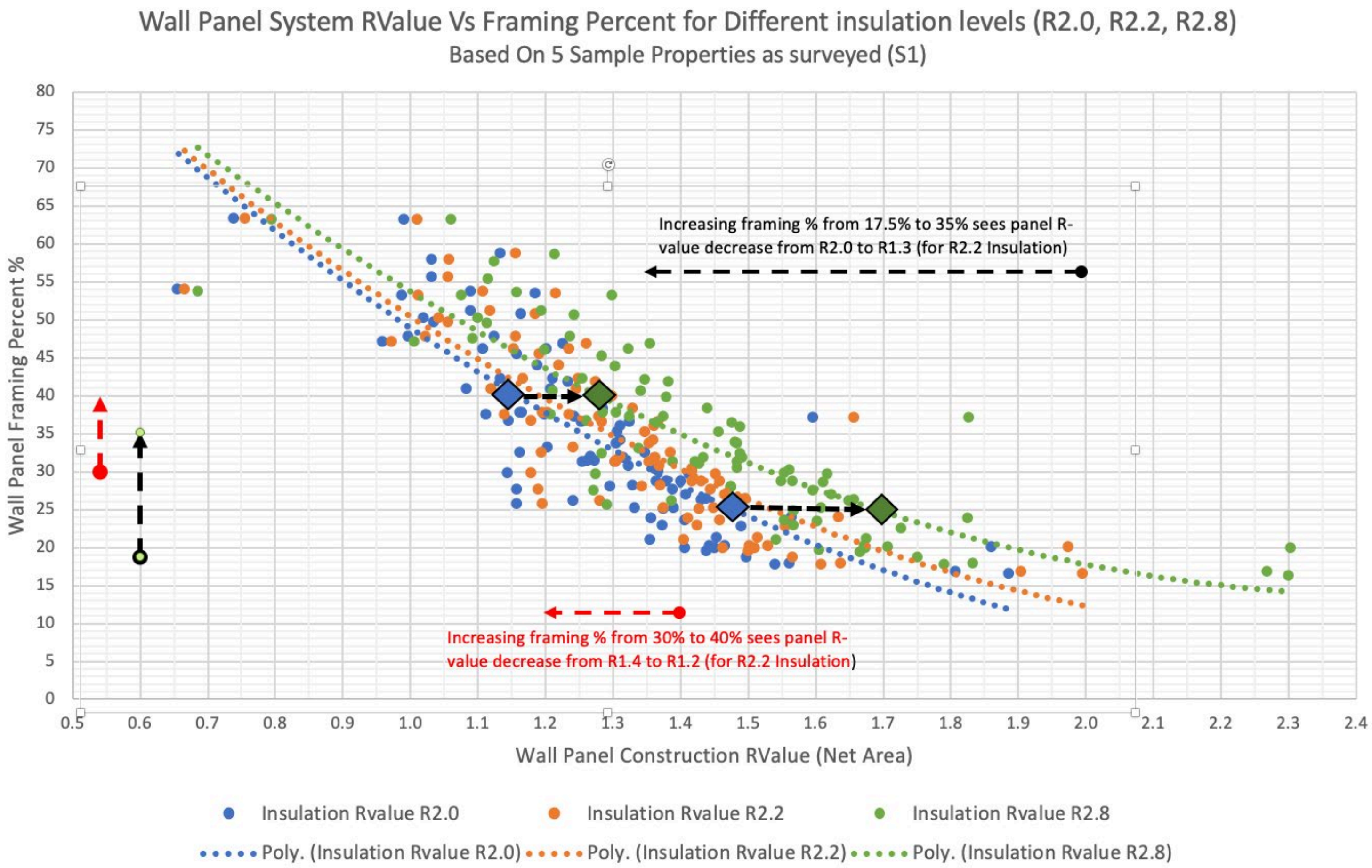


Figure 18: Wall panel system R-value vs percentage of framing for different insulation levels

If we refer to Figure 18 above, we can see that increasing the framing content by a third, from 30% to 40%, will reduce the panel's construction R-value from 1.4 to 1.2, for R2.2 insulation. Similarly, but to a greater extent, doubling the framing percentage from 17.5% to 35% will see the panel's construction R-value reduced from 2.0 to 1.3, with R2.2 insulation installed. The reverse is also true in that reducing the framing content will see an increase in R-value of similar proportions.

Furthermore, as can be seen (in Figure 18 above) by the horizontal arrows with blue and green diamonds at either end, moving from R2.0 to R2.8 insulation at 40% framing content increases wall construction R-value from approximately R1.15 to R1.30. At 25% framing content moving from R2.0 to R2.8 insulation increases wall construction R-value from approximately R1.47 to R1.70.

In addition, openings (windows or doors) have much lower R-values than a typical insulated timber frame wall. This results in the opening not only reducing a wall's R-value due to the additional framing in the net area of the wall (and subsequently less area of installed insulation), but also because that part of the gross wall area (i.e., a window or door) now has a significantly reduced R-value.

2.1.3.3 Volume-derived framing percentages

One of the outcomes from this research is a better understanding of the methods used to accurately determine framing percentages in walls. Panel framing percentages are important as they are indicative of the thermal performance of the wall. We now know the relationship between framing percentage and wall R-value, the impact of changing framing percentages (i.e., reducing to 25%), the other factors that also contribute to heat loss, and the effect of different levels of insulation.

Beacon's research suggests that a wall panel's framing percentage provides a good indication of its R-value. This can be calculated very accurately or applied as a rule-of-thumb (for example, see Figure 18 above).

From initial discussions with BRANZ and representatives from the frame and truss industry, it was discovered that there was no established method to accurately and efficiently determine wall framing percentages, as it had never been required previously. In light of this, a method was developed which consisted of a mix of on-site measurements and the use of panel production drawings (with panel layout, panel elevations and cutting lists), provided by frame and truss companies. The site measurements were largely to confirm the details on the production drawings and to identify timber added on site (e.g., for fixings). In addition, site measurements were important as they allowed the research team to observe and identify a range of related factors such as of weak points, gaps, workmanship and the type and quality of insulation (where installed). While highly accurate, this method was time consuming and expensive and required significant amount of manual data entry.

During the initial stages of the original research, it was observed that panel production drawings included the gross timber volume (m^3) used to manufacture each panel. The gross timber volume included waste produced in the cutting process.

Working with an experienced frame and truss detailer, an exercise was undertaken to see if the wall panel volume figure could be accurately converted to a percentage of framing figure. This was done by comparing the framing percentages calculated for a number of the original 47 case study house examples from Stage One of Beacon's original Wall Project research. This data was utilised alongside the timber volume and a 'waste factor' provided by the frame and truss company. The results aligned 99-100%. See Table 7 in Appendix One: Modelling results summaries.

This information is produced relatively easily by frame and truss companies and could be added to panel production drawings or supplied separately in a tabulated form, including a conversion to wall R-value. This could potentially provide customers, architects and council with an indication of framing content and likely wall panel R-values (or whole house wall R-value). With some additional research it could also be extended to provide an indication of embodied carbon ($C0_{2e}$) within the timber component of the wall panel.

3 Part Two conclusions

Wall construction R-values of recently built house (Base case S1)
Based on a dataset of five representative houses built in 2019, this research demonstrates that complying with the NZ Building Code (using definitions outlined in H1/AS1) produces houses with wall construction R-values less than R1.5 (R1.2 – R1.4), even with R2.8 insulation installed.

These results indicate that the overall thermal resistance of external walls (as-built) is well below recommended levels and also below the required minimum of R1.5 in NZBC Clause E3/AS1. Wall panels with large areas of thermal bridging and a variety of weak points are likely to present as a pathway for excessive heat loss (i.e., rendering heating inefficient and/or ineffective) and therefore a condensation and mould risk, especially if the ceiling and underfloor are well insulated.

Upgrading weak points
The largest single increase in wall construction R-value identified in the sample is attributed to the floor slab edge being insulated **(1Up).** Insulating the floor slab edge (1Up) on single level houses improves the whole house wall construction R-value by around **40%** (range of 35-44% across the sample) when compared with the Base case **(S1)** R-values. Applying 1Up and increasing insulation from R2.2 to R2.8 increases R-value by over 55%, (an increase of R0.72), from approx. R1.30 to R2.02.

Upgrading five typical weak points together **(5Up)** produces a much smaller increase in wall construction R-values. For walls with R2.2 insulation installed, the increase is **11%** or R0.14 (from R1.30 to R1.44) Applying 5Up and increasing insulation from R2.2 to R2.8 increases R-value by 21%, (R0.27), from approx. R1.30 to R1.57.

When all six upgrades are implemented **(6Up)**, the increase in averaged whole house wall construction R-value for the five sample properties is 55% (modelled with R2.0 insulation), 58% (R2.2 insulation) and 68% (R2.8 insulation). The majority of the increase (80%) is due to the slab edge being insulated.

These results reveal that upgrading weak points can have a significant positive impact on whole of house wall system R-value. However, apart from insulating the slab edge, the impact of upgrading individual weak points (i.e., external corners, internal corners, internal wall junctions, above the top plate, and the midfloor perimeter on two level houses) is comparatively minor (<3% per weak point).

Limiting framing to 25%

Limiting wall framing to 25% (from an average of 32% across the five house sample) has a small positive impact on wall system R-value. For the Base case (S1) walls, reducing framing to 25% would result in an overall wall R-value increase of 6% for R2.0 insulation and 8% with R2.8 insulation. This is still well below the intention of NZ Building Code Clause H1 and only just achieves NZ Building Code Clause E3/AS1 (minimum R1.50) with R2.8 insulation. R-value increases due to limiting framing to 25% are greater (10 -17%) when weak points are resolved, especially when insulating the floor slab edge.

Reducing framing to 25%, applying upgrade 1Up and replacing R2.2 insulation with R2.8 insulation lifts average wall construction R-value across the sample from R1.30 to R2.30 (a 77% increase).

Increasing insulation R-value

While it is clear is that R2.8 insulation provides the highest construction R-values modelled and R2.0 the lowest, the difference between them is not large, especially at higher framing percentages. For example, moving from R2.0 to R2.8 at 40% framing sees construction R-value move from R1.15- R1.27 an increase of R0.12, around 10%. At 25% framing, the increase is from R1.47 to R1.70, an increase of R0.23 or 16%. Although increasing insulation from R2.2 to R2.8 results in a moderate increase in total wall construction R-value (approx. 8 -15%), it is one of a number of interventions that, when applied collectively, make a meaningful impact on wall R-value.

Addition of openings

The addition of an opening (windows or doors) in a wall panel increases the amount of timber framing within that panel and therefore reduces wall construction R-value. Moreover, the percentage of framing in panels tends to reduce as panel size increases for both panels with and without openings.

Windows and doors have much lower R-values than a typical insulated timber frame wall. Including an opening in a wall panel not only reduces the panel's R-value due to the additional framing in the net area of the wall (and, subsequently, less area of installed insulation) but also because that part of the gross wall area (i.e., a window or door) now has a significantly reduced R-value.

These relationships imply that openings should be carefully located in larger panels (aligned with standard stud spacings), and opening size should be minimised if wall construction R-values are to be optimised.

Declaring wall panel framing percentages

The evidence gathered in Stage One and Stage Two of the Wall Project indicates that there is a lack of consideration given to the thermal performance of walls throughout the entire design, compliance, fabrication and construction process. However, given that the percentage of framing is a good indicator of wall panel construction R-value, it may be useful to include nominal framing percentages alongside timber volume (m^3) on panel production drawings and associated documentation to increase industry and market awareness of the thermal performance of walls.

Working with an experienced detailer, the research team has discovered that converting wall panel volume (m^3), which is noted on panel production drawings, to a percentage of framing is relatively straightforward and very accurate. This information could be extended to indicate approximate construction R-values (with different levels of insulation), and potentially also highlight a carbon emissions factor.

Summary

Given the challenges involved in reducing framing percentages (see Part One of this report), and the relatively small R-value gains of reduced framing ratios in a typical 90mm stud wall, reducing framing on its own is a limited strategy. Similarly, increasing insulation to R2.8 and applying upgrades of five common weak points (5Up) on their own will not produce walls with construction R-values over R1.80, even with framing limited to 25%. Applying 1Up (vertical slab edge insulation) on its own increases wall construction R-value significantly (~40%). When combined with R2.8 insulation, applying 1Up results in R-values around the NZ Building Code H1/AS1 minimums of R1.9/R2.0 (modelled across the sample, the range was R1.70 – 2.38).

If there is a desire to achieve wall construction R-values greater than R2.0 (which is, internationally, a low target), yet retain current design, manufacture and construction of walls then a number of principles should be followed. These include:

1. Always specify R2.8 bulk insulation (in 90mm walls)
2. Ensure the vertical slab edge is properly insulated and remains so for the life of the house
3. Optimise framing – eliminate all unnecessary framing not required for structure, weathertightness or fixings
4. Minimise complexity in the wall configurations (to eliminate internal and external corners)
5. Minimise the number and size of openings and try to place them in larger panels and,
6. Declare nominal framing percentages on panel production drawings

However, applying all these principles consistently across the design, fabrication and installation of wall panels is unlikely to occur, due to the many factors involved. Furthermore, thermal bridging through the timber framing is still ultimately not addressed by this approach and will continue to be a source of heat loss and potential location of condensation and mould. An alternative approach, and one that will resolve many of the issues highlighted above, is to install an additional thermal layer on the inside or outside of the existing wall system. This creates a thermal break between the timber framing and the external environment as well as providing space to increase insulation thickness by 50% to approximately 140mm (from 90mm).

Part Three

Advanced framing & insulation solutions

Part Three: Advanced framing and insulation solutions

Part Three of the research explored practical ideas for improvement of the thermal envelope: identifying advanced framing and insulation options, and holding a workshop to explore whether these could be adapted to modify existing 'typical' framing solutions. The bulk of the information and results from this workshop can be viewed as a video of the main workshop session which was held on 15 October 2020 and is available for viewing from the following link: https://youtu.be/_altm5o6jcA

The information and discussion from the workshop helped also to inform both Part One and Part Two of the research described in this report.

1 Approach

The aim of this aspect of the research was to explore advanced framing and insulation approaches to highlight potential solutions to the issue of thermal bridging and higher framing ratios. Discussions with the regulator, industry and research organisations during Stage One of the Wall Project identified the potential for practical, cost effective and innovative ways of constructing timber-framed walls that would have much more consistent and improved thermal performance.

The intended focus was on **pragmatic** and **buildable** solutions that could be shared and widely adopted amongst industry, using familiar framing approaches and with little complication and as few changes as possible to current regulation and/or compliance regimens. As a result of this pragmatic approach, the more complicated 'systems' and 'product' based solutions - such as commercialised SIPs panels - were not to be a focus). The aim was to explore whether current building techniques, that are based on reasonably standardised NZS 3604 type approaches, could be pragmatically modified to result in a radical improvement to the thermal envelope (e.g., offset or battened out double wall systems in standard 90mm frame).

The aim of the workshop was to provide insights into:

- What has been done in NZ to date?
- What works well – what could/should be done differently?
- What are the most cost-effective options currently available?
- What are the benefits – have they been tested and/or can the costs/benefits be easily quantified?
- What are the barriers / challenges to the identified advanced framing and insulation solutions?
- What in the regulatory and industry environment would need to be resolved to enable advanced framing solutions to become industry standard e.g., do they have the potential to become an acceptable solution? Are industry stakeholders such as frame and truss manufacturers supportive?

With these aims in mind, Beacon developed a workshop format and requested presentations from known innovators in the field of thermally improved framing and insulation systems.

Originally the workshop was intended as a face-to-face session involving a wide cross section of industry. Due to the impacts of COVID 19 and subsequent lockdown events, a decision was made to host the event as a live streamed webinar.

Workshop Date / Time: Thursday 15 October 2020: 10am – 12.30pm
Workshop duration: 2.5 hrs
Location: Online via zoom webinar (recorded for upload and streaming after the event)
Audience / Attendees: The workshop was targeted at expert industry stakeholders who could contribute time, industry knowledge and expertise to the workshop process. The workshop attracted nearly 100 workshop participants drawn from a broad cross section of the residential construction industry and representing:

- Frame and truss industry
- Building product suppliers
- BRANZ
- MBIE, EECA
- Kāinga Ora
- NZIA, ADNZ and other design and training organisations
- Designers, builders, construction companies

Workshop Programme (approximate timings):

10.00 am	Welcome / Introductions / Context: Verney Ryan, Beacon Pathway Inc
10.15 am	Current wall performance: Guy Penny, Beacon Pathway Inc
10.30 am	The Zero Energy House: Jo Woods & Shay Brazier, Re/volve Energy
10.55 am	Alternative wall systems: Glenn Murdoch, Theca Architecture
11.20 am	Thermally improved construction details: Jason Quinn, PHINZ
11.45 am	Current exemplars and the Superhome approach Superhome Movement: Bob Burnett, Damien McGill, Dan Saunders
12.10 pm	Medium density housing framing solutions Shawn McIsaac, Oculus Architectural Engineering
12.25 pm	Wrap up – final questions and panel viewpoints
12.30 pm	Session End

2 Advanced framing and insulation exemplars

Following the workshop, several of the workshop presenters were approached to share some basic information about each of their preferred solutions to thermal bridging in walls. These ranged from the practical as-built application set out in the Zero Energy House (a single example) through to numerous different approaches examined as part of a large project for the Passive House Institute of New Zealand.

The information provided below, from those who agreed to share their approach, is intended to provide the reader with examples of different advanced framing and insulation approaches. It is important to point out that these details and accompanying information are in no way intended as building advice and should not be copied and replicated without considerable further research as to their applicability and suitability.

Furthermore the information that has been supplied is reproduced here with minimal editing for comprehension and to ensure some consistency of style. No warranties are implied in the claims made in the text from the various authors.

Additional illustrations and explanations of the showcased exemplars are available from the video recording of the workshop session and viewers are directed to this for more in-depth information. The video is available on the Beacon Pathway website and directly available at the following URL https://youtu.be/_altm5o6jcA

2.1 The Zero Energy House: Jo Woods & Shay Brazier, Re/volve Energy

[Please Note: Text and diagrams in this section supplied by Jo Woods and Shay Brazier and minimally edited by Beacon]

Wall case study details: Zero Energy House
Project owners: Shay Brazier and Jo Woods
Climate Zone 1 (Auckland)
Designer: A Studio Architects (Architecture), Shay Brazier and Jo Woods (thermal, mechanical, and electrical engineers), Morconsult (structural engineers)
Builder: O'Shannessy Builders (now Visionary Construction).

General description of approach: Two framed layers including one 90mm stud layer without any dwangs and one 45mm horizontal batten layer. Insulation including in both stud and batten layers (continuous). The location of the batten (adjacent inside or outside of the stud) depending on whether the cladding is vertical or horizontal.
Framing: 90x45 studs 45x70 battens
Insulation Type: Polyester
Cladding: Vertical and horizontal weatherboard
Suitability for range of cladding types? Yes
Specific structural engineering required? Yes

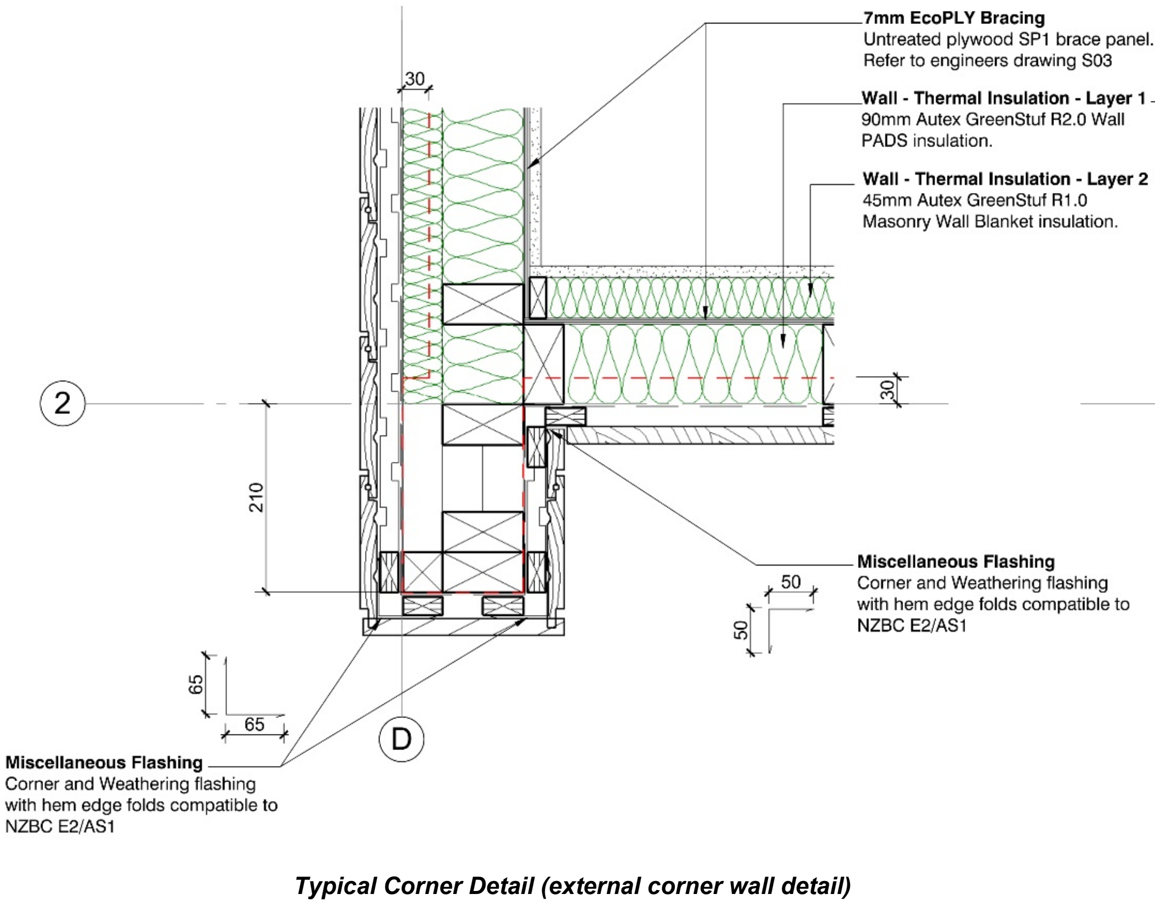
Lessons learned:
Benefits of system:

- Fairly minor change over standard practice but provided significant improvement in thermal performance. It was therefore instrumental in helping to achieve good thermal comfort without mechanical heating and net zero energy.
- Standard building materials used.
- Less material and labour to produce frame.
- Less cutting of insulation if the building design allowed standardised frame sizing.
- Less labour to install wires and pipes as they could be run in the batten layer. 90mm pipework was run inside the framing and blocked out to avoid impacting thermal performance of envelope.
- Suitable for pre-nail or build on site.
- Suitable for vertical or horizontal cladding by changing batten location (inside or outside the stud).
- Operational energy use of the building typically results in an annual energy bill of $1,000 including electric vehicle charging.

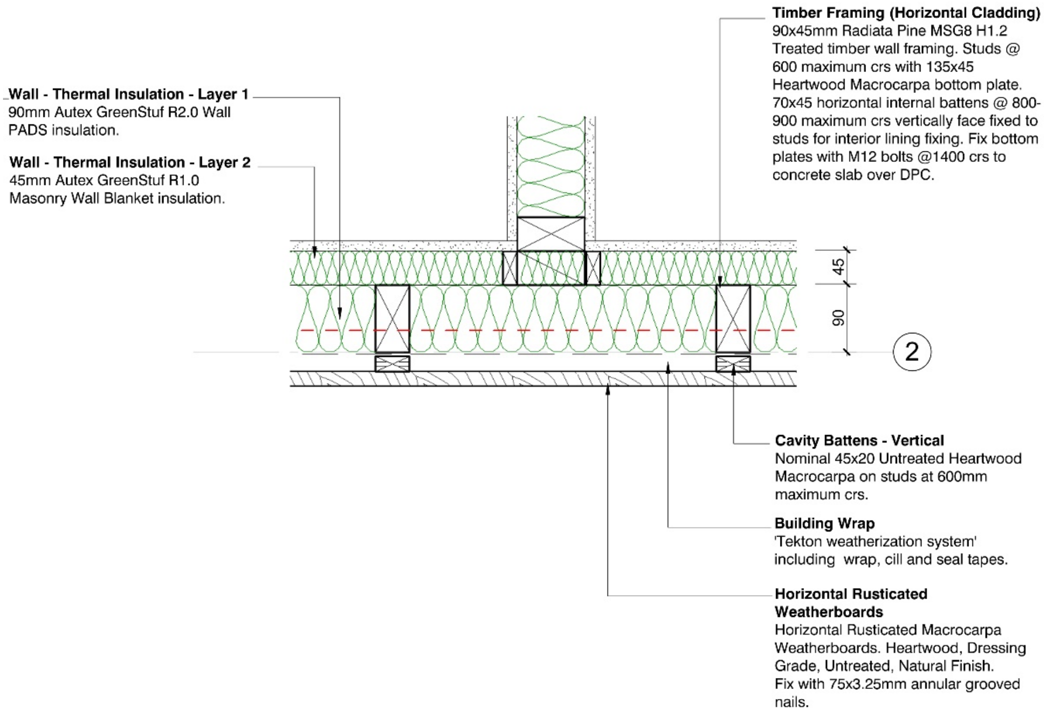
Challenges of system:

- Pre-nail was challenging as the framing approach was new to the F&T company. Plans were not followed for all the details in early design iterations, instead adopting standard F&T approaches.
- Difficult to transport and erect wall frames without bracing elements.
- Additional costs to this project due to specialist structural engineers report and architects needing to produce specialist pre-nail drawings for the F&T company.
- Locating bracing elements was challenging due to the balloon framing.
- Project included significant detail and careful insulating compared to business-as-usual construction which added some time, e.g., insulating corners, lintels etc. As with most timber framed buildings insulation needed to be installed in some locations prior to the building paper going on.
- Would require upskilling of industry at both design and build stages for it to be effective.

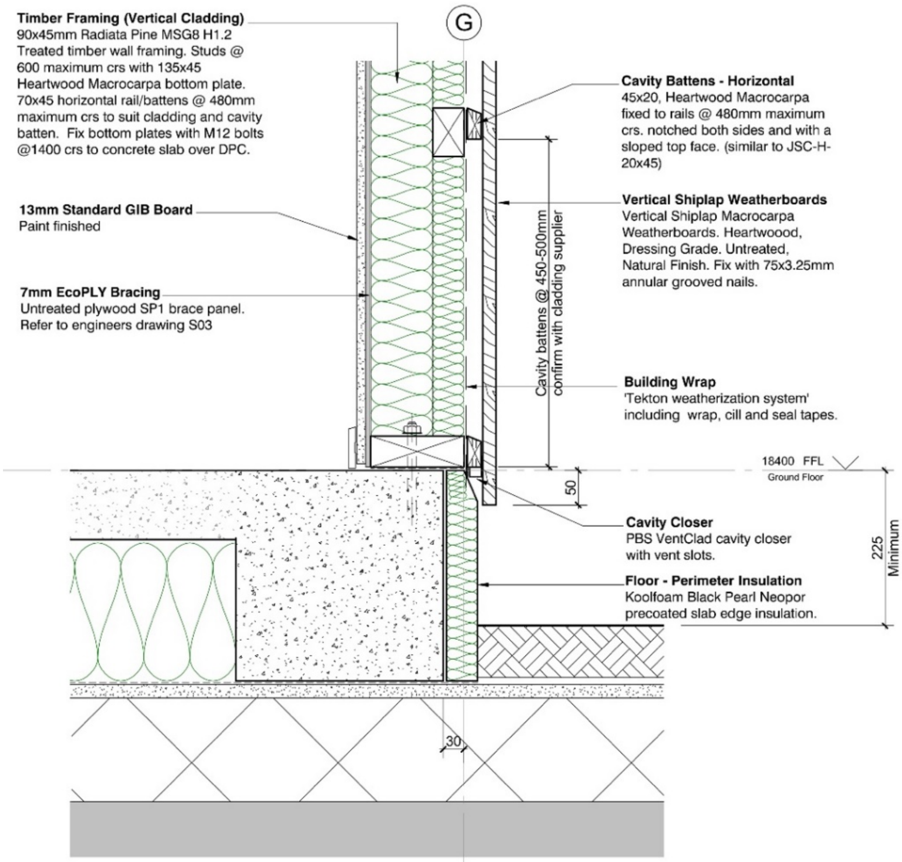
Building consent issues noted (if any): None other than specialist structural engineering report required at the time.
Cost comparison: Unknown
Details / diagrams / drawings: Details developed by Shay, Jo and A Studio and drawn up by A Studio.



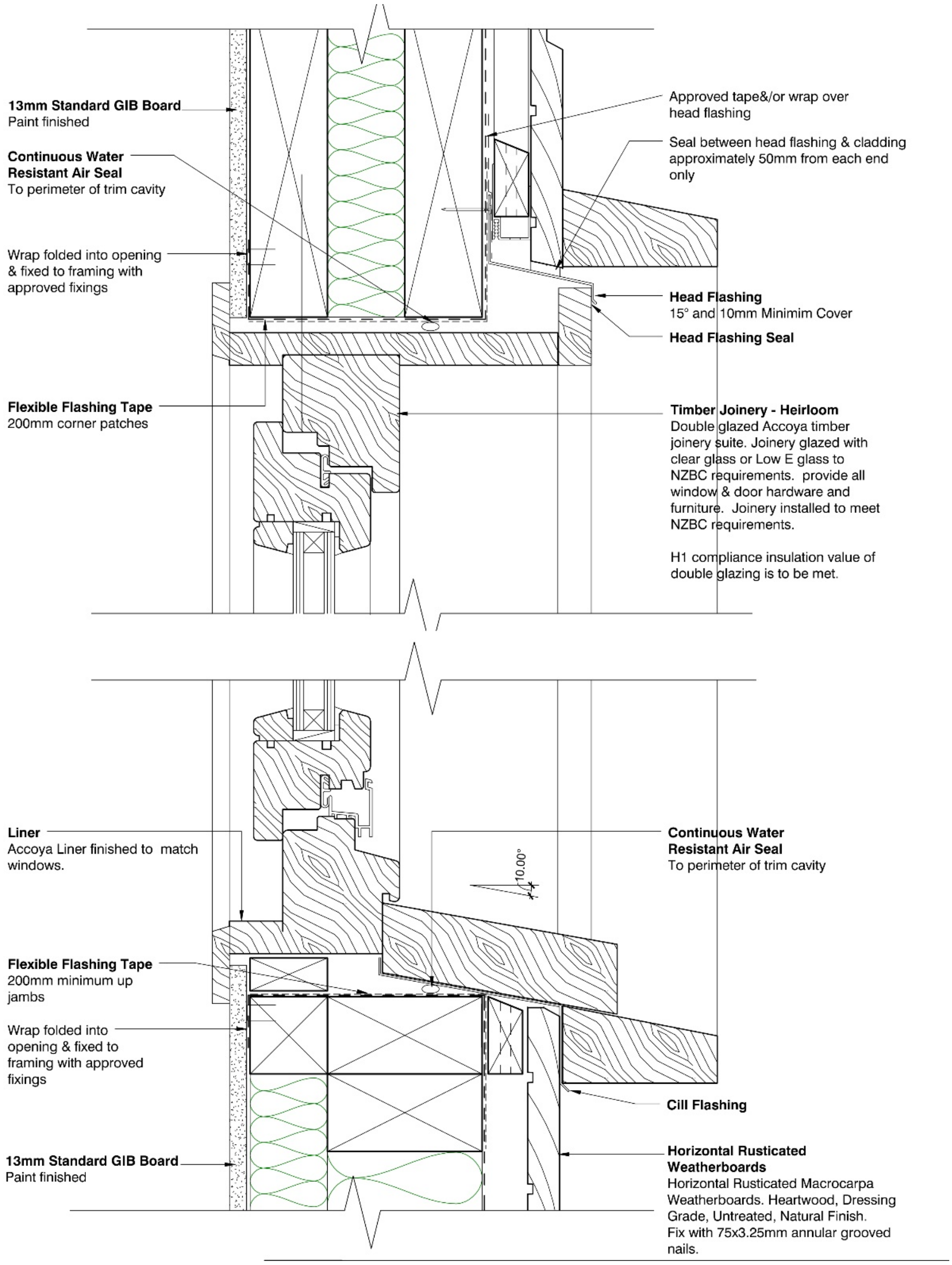
Typical Corner Detail (external corner wall detail)



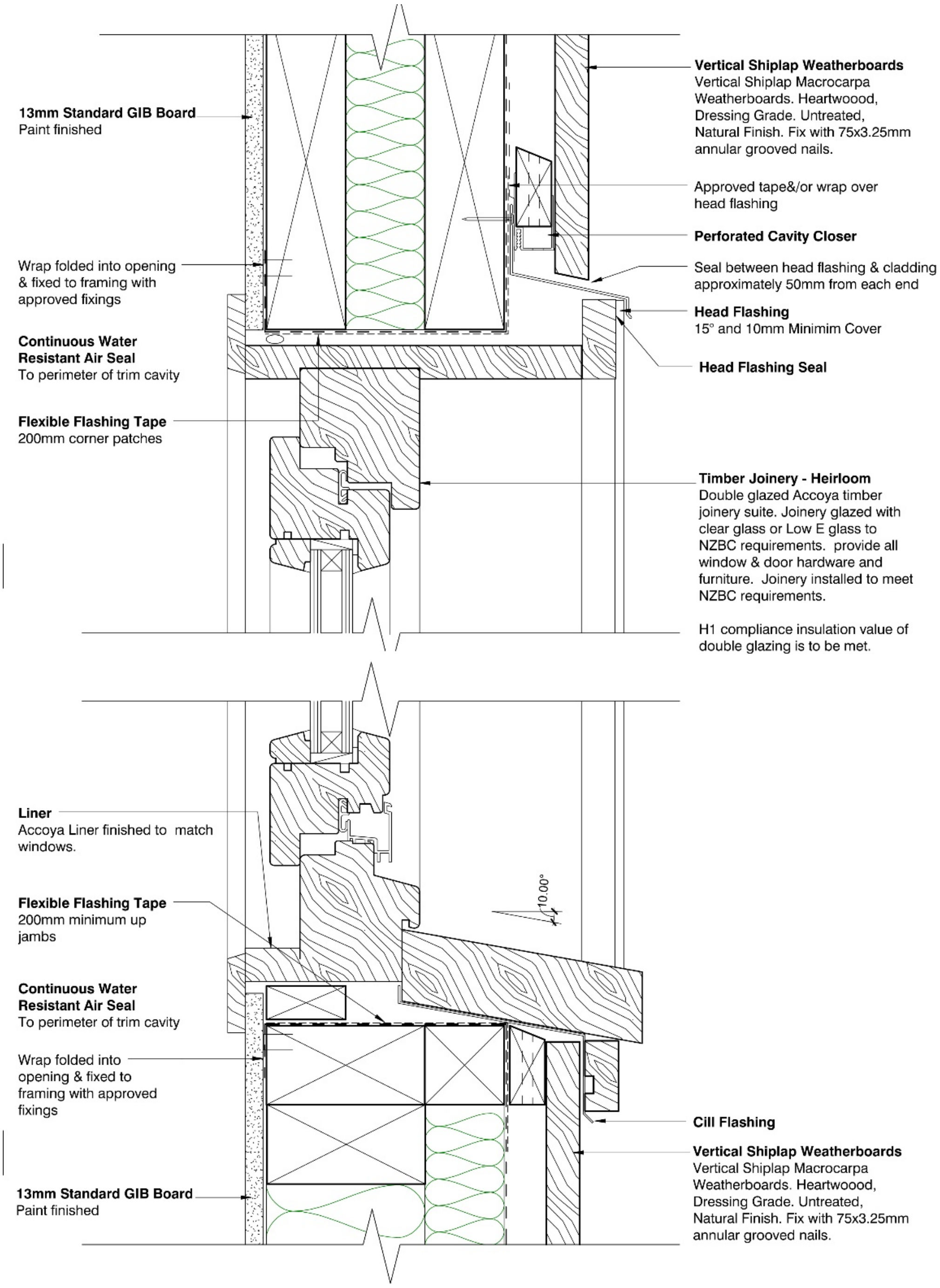
Typical internal to external wall junction



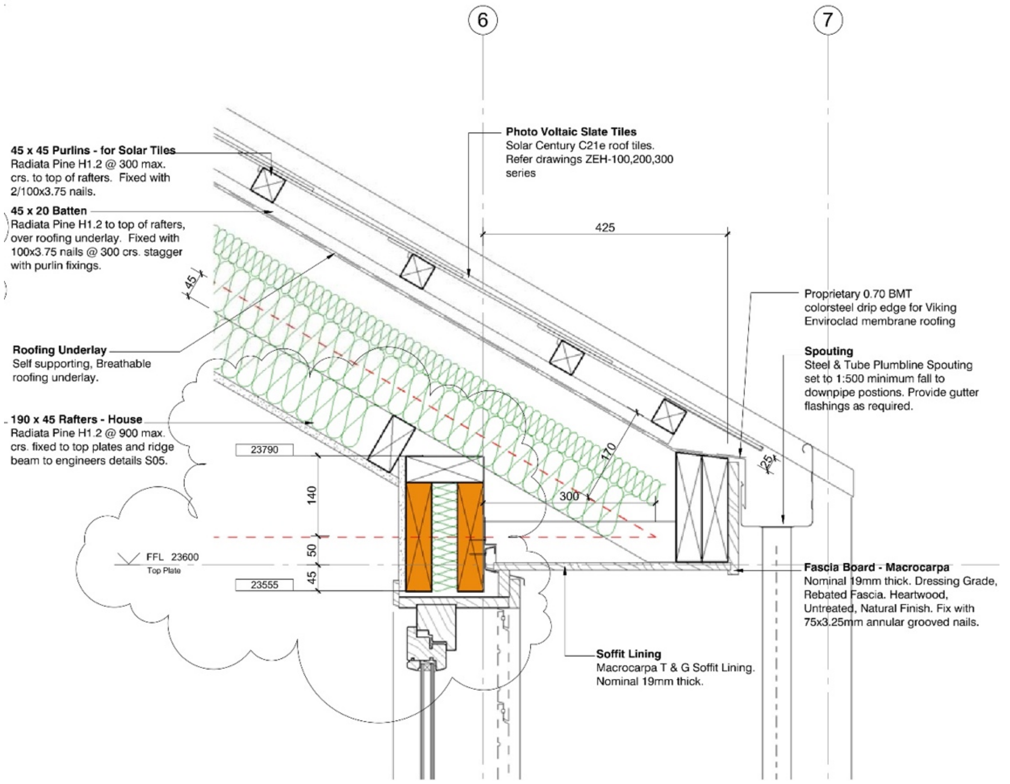
Typical slab/wall to floor detail



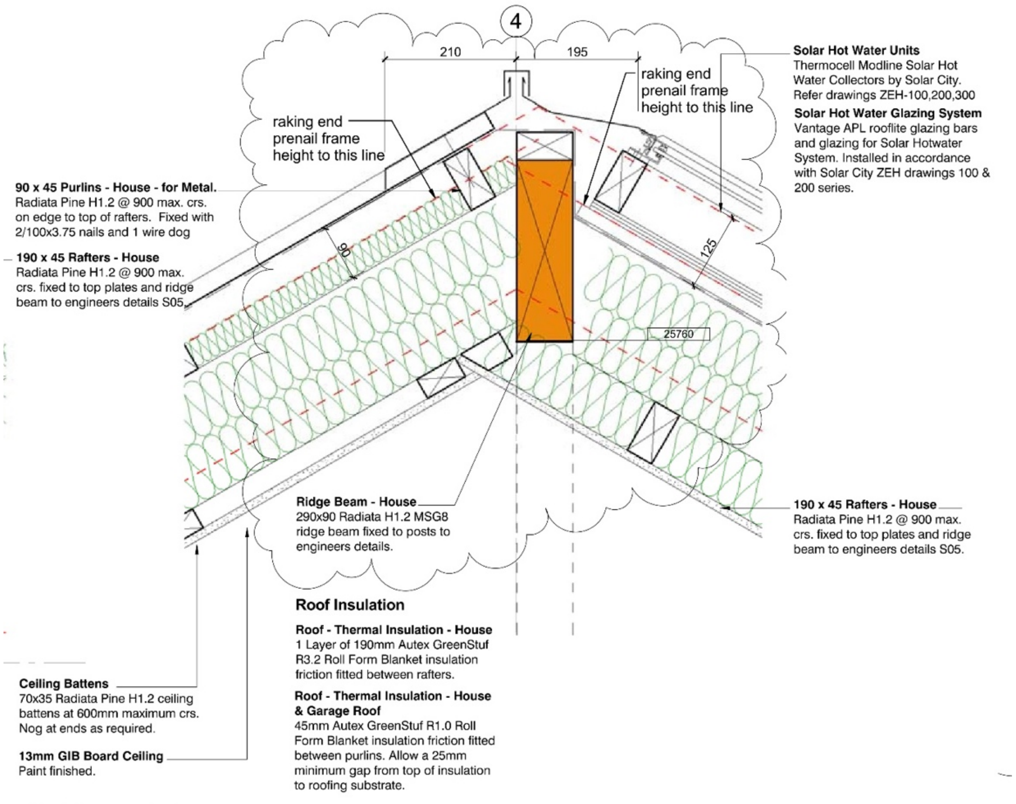
Typical window junction cross section (showing internal batten/external stud)



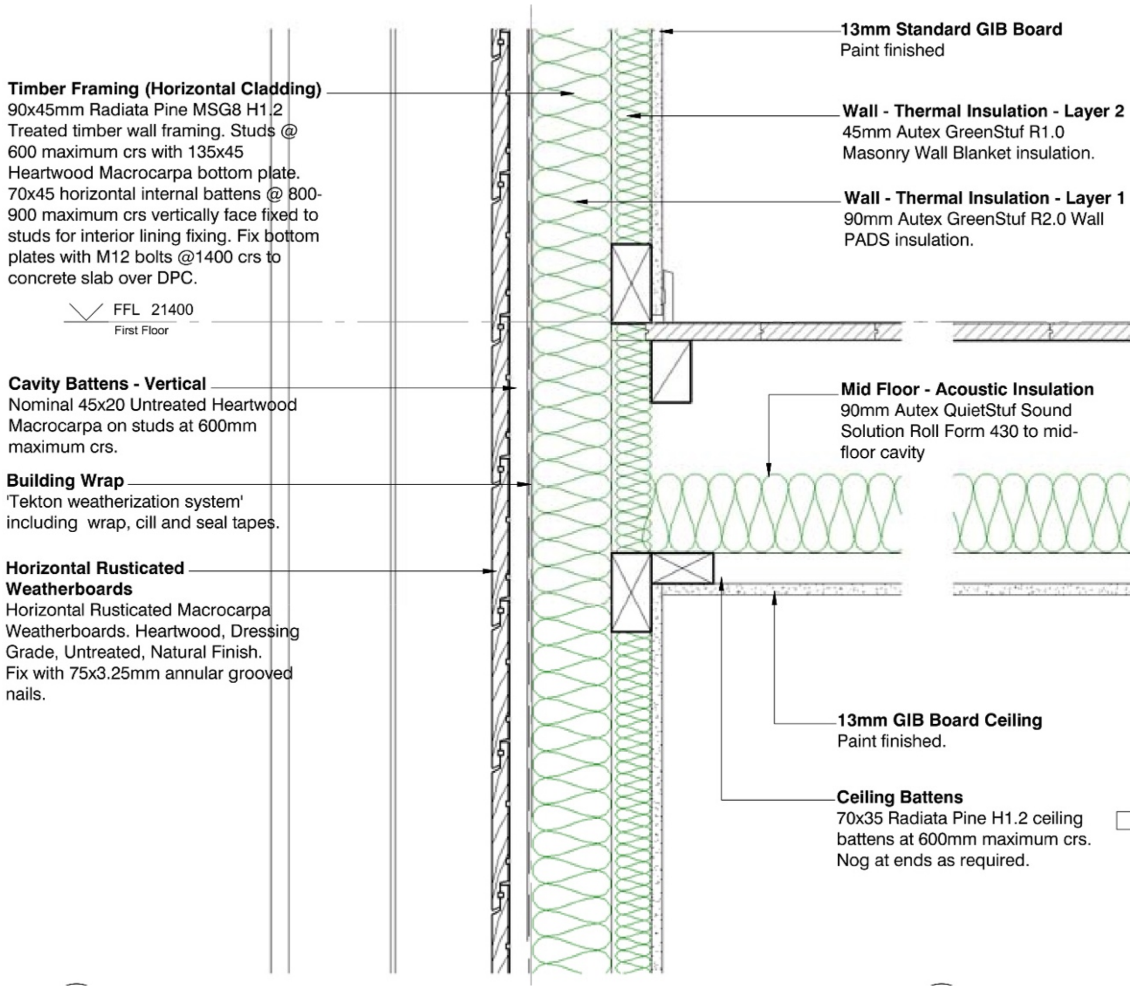
Typical window junction cross section (showing external batten/internal stud)



Typical wall to ceiling/roof cross section



Typical wall to ceiling/roof cross section



Typical midfloor detail

Suitability for development of framing solution into an acceptable solution:

The Zero Energy House approach would be relatively easy to include as an acceptable solution; however, it would require the following:

- A review of the design as an acceptable solution to determine any outstanding requirements for compliance.
- Review of bracing approaches appropriate to the framing details.
- Producing clear information on how to design with this solution for architects and designers. This should ideally include educational resources as well as information set out in the standard, e.g., detailing, standardisation of framing, etc.
- Education of the local authority consenting officers to ensure they understand the solution and how it needs to be designed for consent.
- Education of the pre-nail (frame and truss) companies to understand requirements of this system if developed as an acceptable solution, and any other requirements around design and transportation.

- May require additional procedures to develop safe erection methods as well as further education of the construction industry to ensure they understand requirements around best practice insulation installation.

To increase chances of adoption by the industry the educational resources outlined above are recommended alongside information on why this framing system could be preferential to business-as-usual framing (see benefits above).

This approach would require some upskilling of the industry. The concept is a minor change from the current standard stud design and therefore it would probably be reasonably easy for the industry to adopt. There could be some challenges around locating permanent structural bracing elements within the building envelope.

Online links to further information: https://zeroenergyhouse.co.nz

2.2 Alternative wall systems: Glenn Murdoch, Theca Architecture

[Please Note: Text and diagrams in this section supplied by Glenn Murdoch and minimally edited by Beacon]

Wall case study: Theca Architecture Standard Details
Project owners: Various
Climate zone: Various (picture shown in Canterbury)
Designer: Glenn Murdoch, Theca Architecture
Builder: Various
F&T company: Various

General description of approach: Structural timber stud framing with no dwangs, exterior sheet bracing, interior vapour control membrane, timber service cavity battens.
Framing: Anything can be used. We have used 90 x 45, 140 x 45 and 200mm plywood I-beams.
Insulation Type: Any bulk insulation can be used. We typically specify dense fibreglass insulation.
Cladding: Suitable for any cladding. Because there are no dwangs in the structural framing, structural cavity battens may be required, particularly for vertical claddings.
Specific structural engineering required? Connection of midfloor ribbon to wall framing.

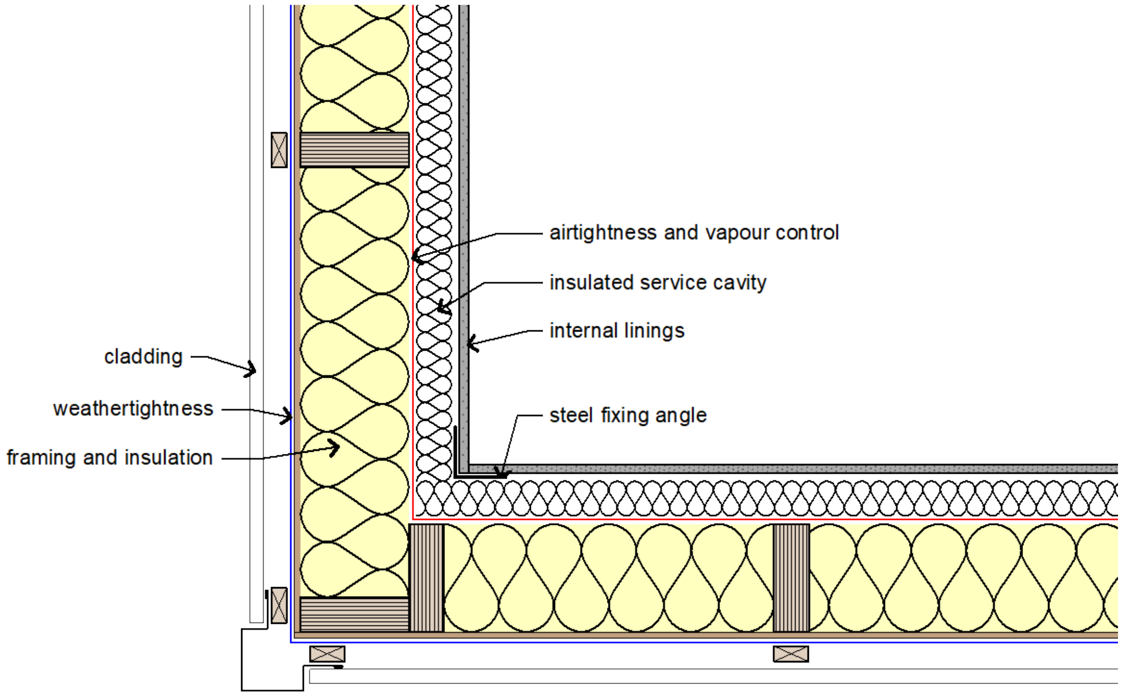
Lessons learned:
Benefits of system:

- Significantly reduced framing proportion
- Significantly reduced thermal bridging at junctions
- Significantly improved thermal performance due to insulation performing at advertised value due to elimination of air movement
- Elimination of interstitial moisture

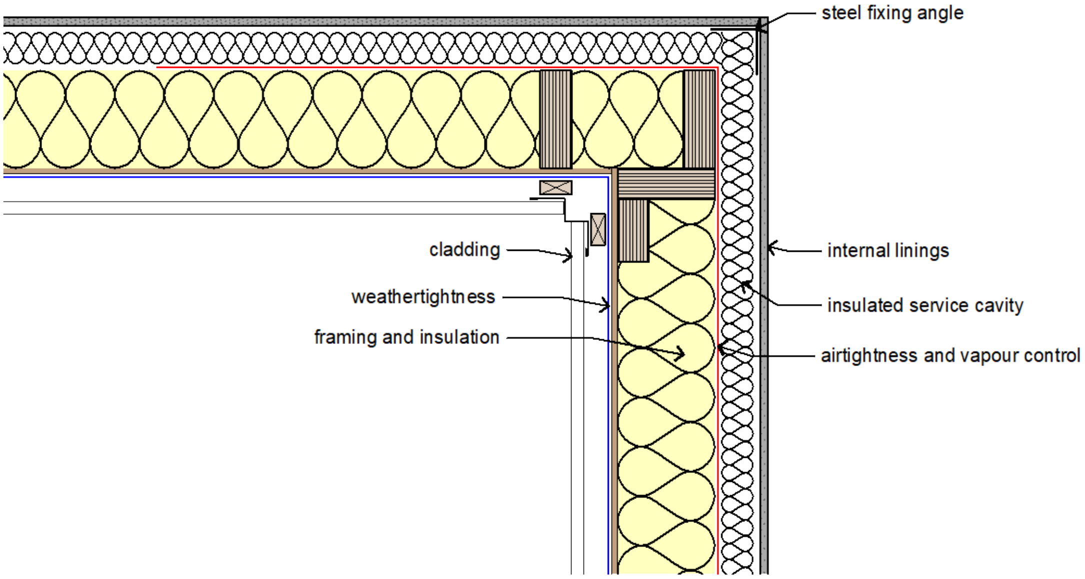
Challenges of system: None identified
Building consent issues noted (if any): None identified
Cost comparison: There is clearly an increased up-front capital investment required in both materials and labour for this system. However, an Equivalent Annual Cost analysis of increased cost and reduced

operational heating / cooling cost shows that a home using this system is cheaper to build, own and operate than a standard NZS 3604 solution.

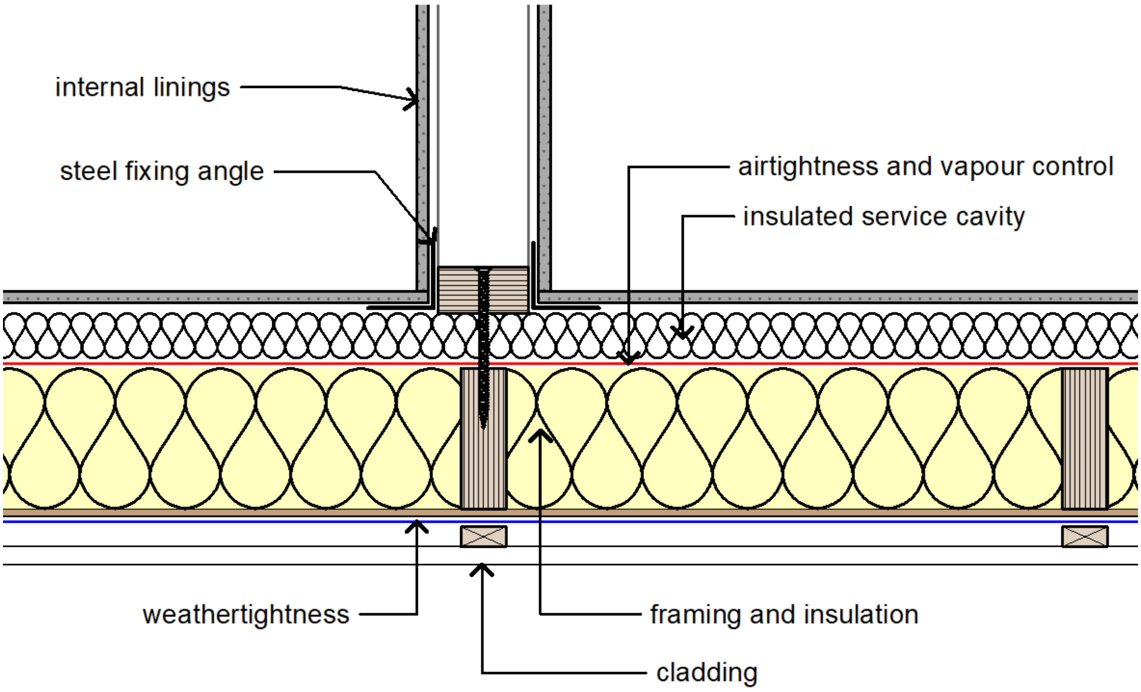
Graphic Details / diagrams / drawings:



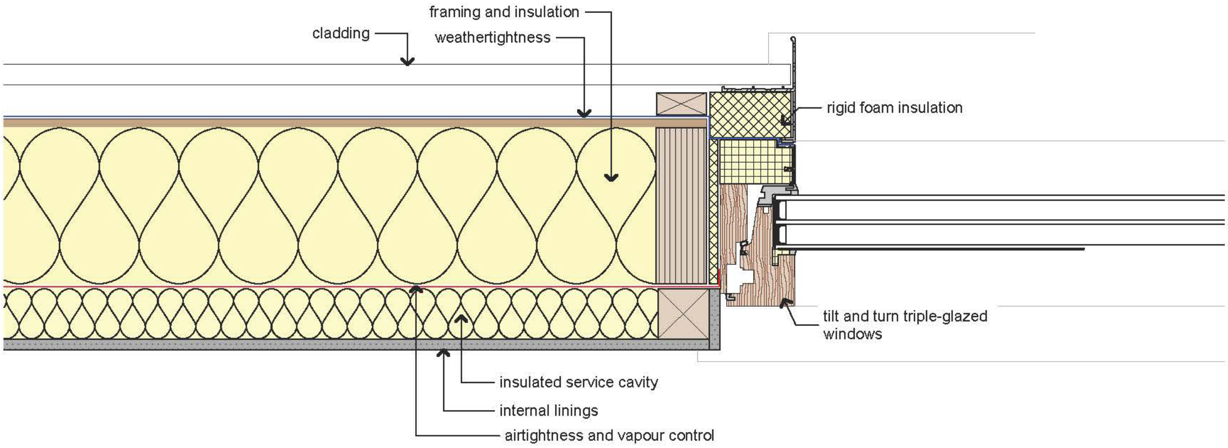
Typical external corner



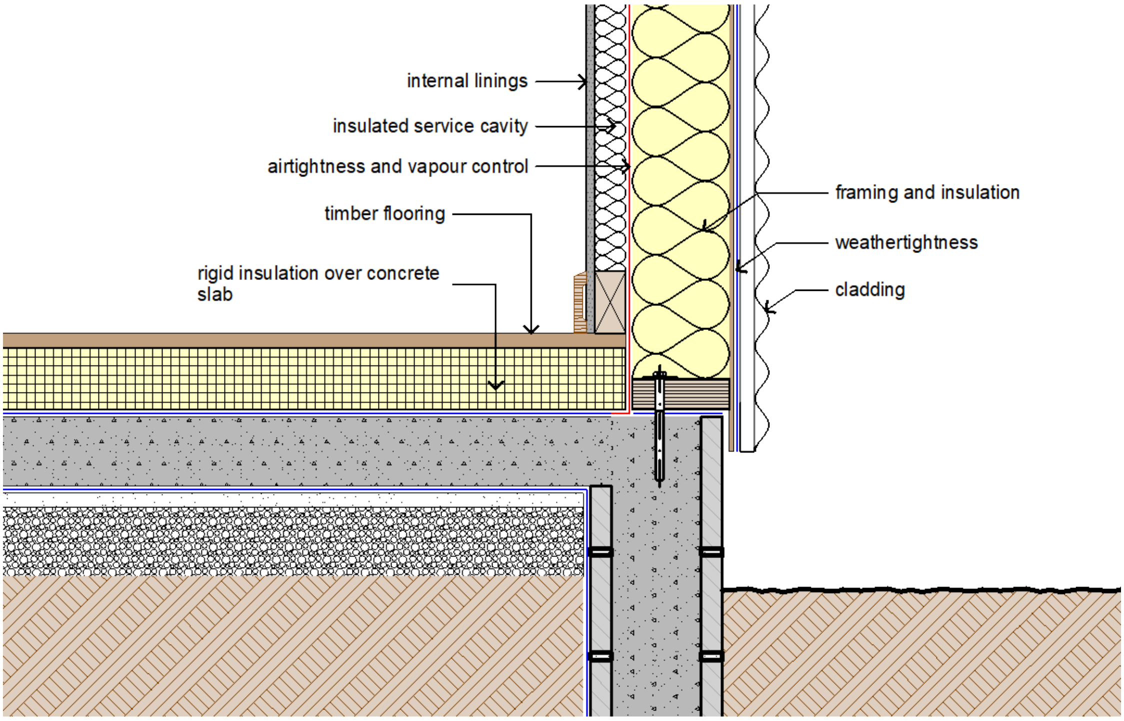
Typical internal corner



External / internal wall junction

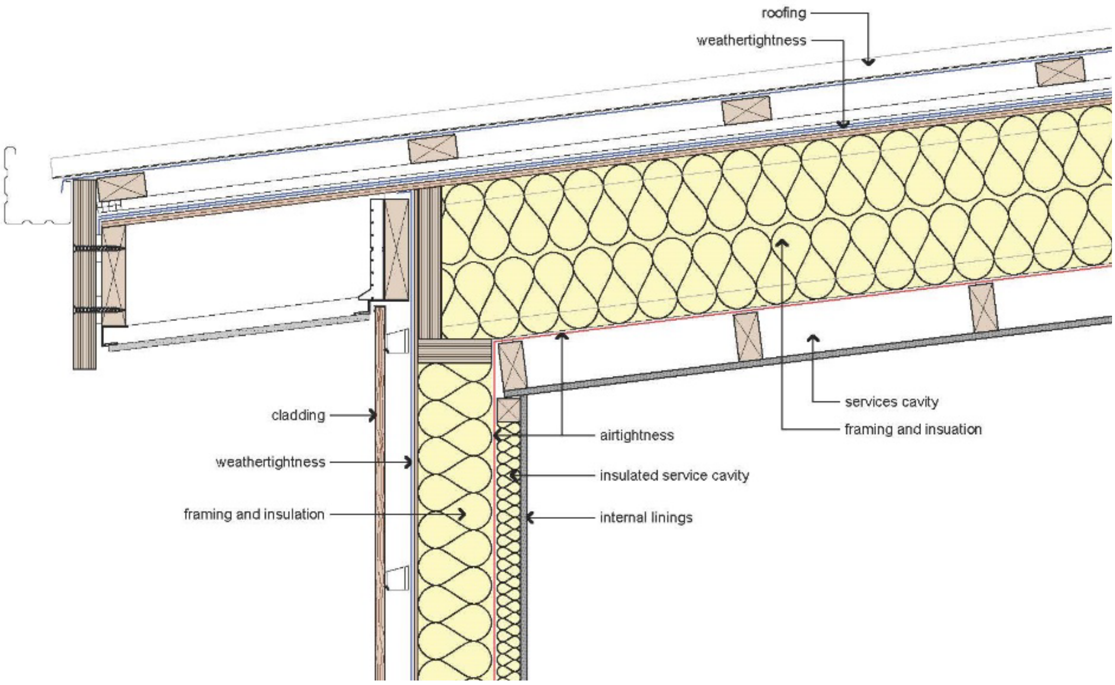


Window jamb

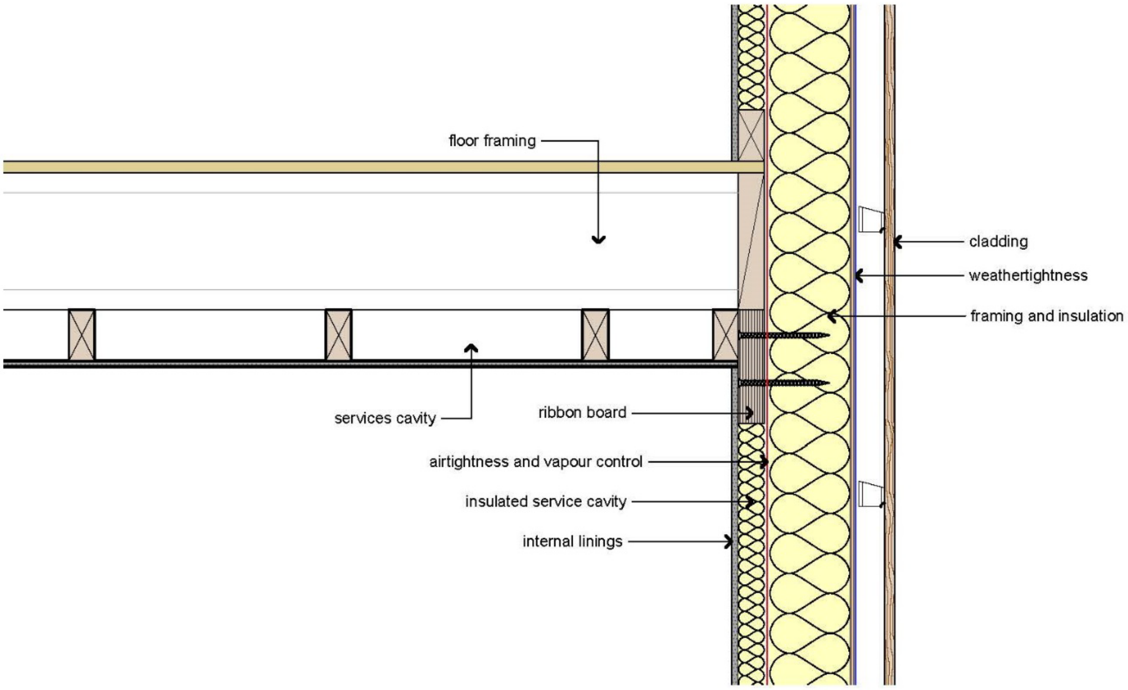


Typical wall / slab junction

Note: Slab can also be insulated on the outside, with the wall overhanging the slab edge by up to 50mm (with 140 framing)



Typical eave



Typical midfloor

Suitability for development of framing solution into an acceptable solution:
Except for the fixing of the midfloor ribbon to the wall framing, the solution is already an Acceptable Solution using NZS 3604. The approach (indicated in the above illustrations) is currently suitable for development into a more detailed and standardised acceptable solution with the addition of the following:

- A simple table of fixing requirements for the midfloor ribbon board.
- Further development of clear information about how to design with this solution for architects and designers
- Supporting information for Council in order to make it easy to consent
- Supporting information for pre-nail companies/builders on construction and detailing
- Supporting information for builders on installation on site including best practice insulation (minimising thermal bridging) and better inspections by BCAs for insulation installation.
- Uptake of inexpensive IR camera usage to find insulation gaps (and assist with continual improvement).

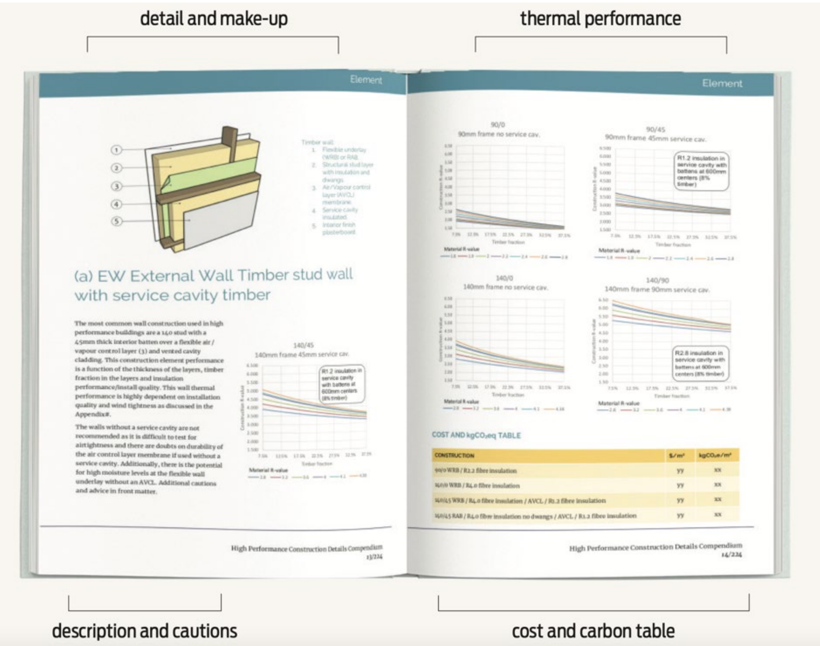
Online Links to further information: www.theca.nz

2.3 Thermally improved construction details: Jason Quinn, Sustainable Engineering Ltd

Jason Quinn (Sustainable Engineering Ltd), working with The Passive House Institute of New Zealand (PHINZ), presented some early findings from a project looking at thermally improved construction details. The project is exploring a set of construction details that have been developed to deliver significantly improved thermal performance compared to typical conventional details. In excess of 100 details have been illustrated and these cover walls, floors, roofs windows and other aspects of typical construction.

The project to develop the details is led by Passive House Institute New Zealand (PHINZ) with funding support from the Building Research Levy. Each of the high-performance details was individually modelled and the results include thermal losses through junctions and corners – both areas that are not currently considered by H1 for code compliance.

The full set of details will be published in a BRANZ study report in the first half of 2021. They will be accompanied by costings and carbon footprint information. For this reason, details are not provided here, and the reader is pointed toward the final report and handbook of drawings produced by PHINZ and BRANZ. For more information please see: https://www.branz.co.nz/pubs/research-reports/

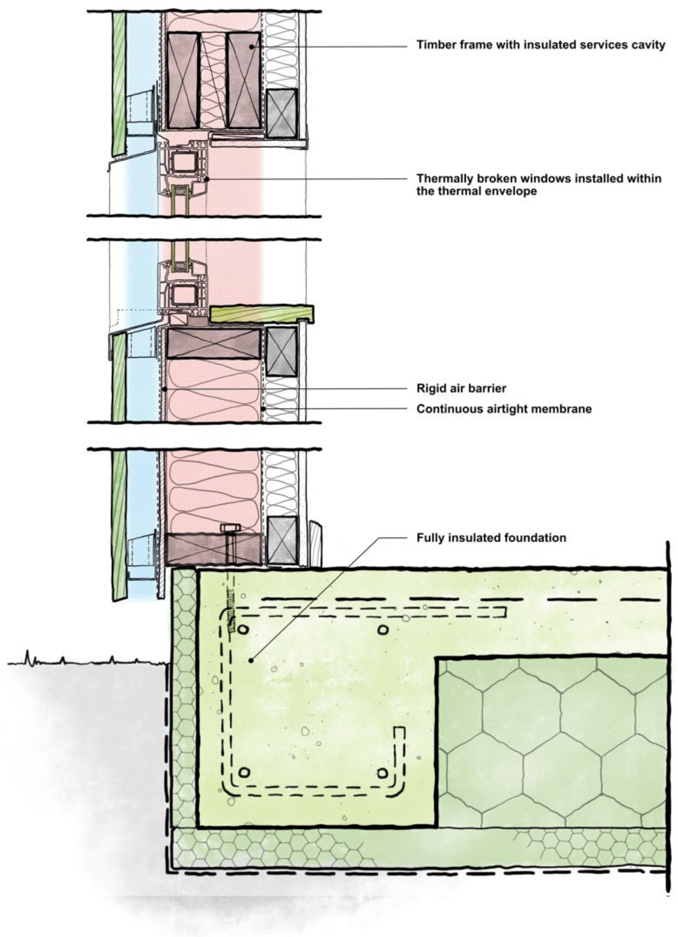


Example from Build magazine showing project output[24]

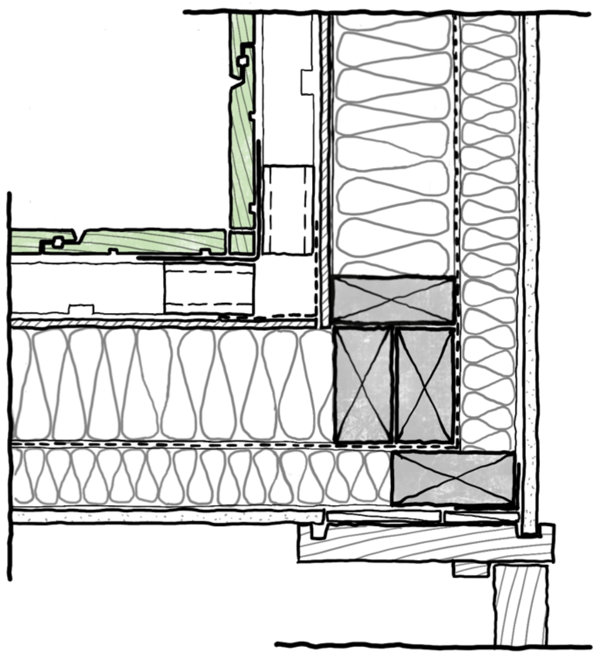
[24] For more information see: Jason Quinn and Elrond Burrell, 2021, High-performance details in BRANZ Build Magazine, 1 February 2021, Build 182

2.4 Current exemplars: Superhome Movement

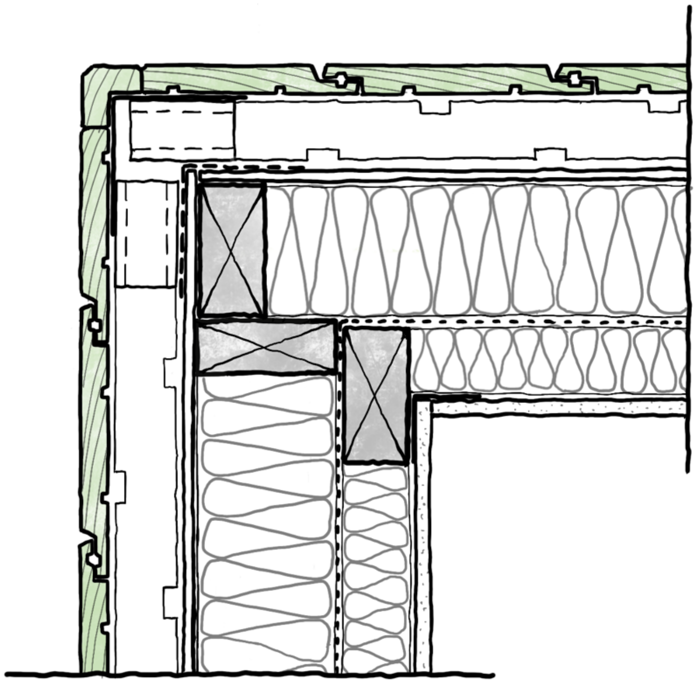
The workshop heard from Bob Burnett, Damien McGill, and Dan Saunders as representatives of the Superhome Movement. In part, their presentation covered innovative approaches to overcome thermal bridging in walls and, in part, it was used to help promote their new document, the ‘‘Healthy Home Design Guide’. Since the workshop took place, the guide has been made freely available online. It contains several illustrations relating to solutions for advanced framing and insulation approaches, as well as other material relating to designing for whole of house improved performance.



An example of one suggested Superhome advanced framing and insulation system utilising an internal services cavity created using a counter batten on the inside of the stud wall



An example of an internal corner detail from Superhome showing reduced thermal bridging in the corner junction



An example of an external corner in a Superhome showing reduced thermal bridging in the corner junction

For more information please see http://healthyhomedesignguide.co.nz/walls---panels-healthy-home-design-guide.html

2.4.1 Superhome Case Study - 9 and 11 Church Square Addington Christchurch

[Please Note: Text and diagrams in this section supplied by Bob Burnett and minimally edited by Beacon]

About: Situated in historic Church Square, Addington, Christchurch, two distinctly different homes replacing an earthquake damaged cottage in 2015 were both the first to be designed and built to the 10 Homestar rating and also signalled the start of the Superhome Movement. 9 Church Square is a single storey 3 bedroom home 117m2 and 11 Church Square two storey 140m2.

They formed part of a vision for demonstrating healthier homes and more sustainable ideals for an energy efficient, low carbon future. Initially both were made available to the public as demonstration homes and featured on the first Superhome Movement exemplar home tours. The aim has been to demonstrate that smarter designed and better built, affordable, warm comfortable healthy homes, were easily achievable using commonly available materials but employing better techniques.

Project Owner/Developer: Bob Burnett
Designer: Bob Burnett, Bob Burnett Architecture
Engineer: HFC Group

Legal description: Lot 2, DP 12122
Planning zone: Medium Density
Site area: 574.63 sqm

Building area 1: 117.78 sqm
Building area 2: 71.40 sqm
Site coverage: 33%
Wind zone: Medium
EQ zone: 2
Corrosion zone: B
Climate zone: 3

Framing: Advanced timber framing prototype. This project was an early prototype and case study project for what became known as GIBFIX Framing

System details.
Studs: 140mm x 45mm LVL studs @ 600 centres,
Dwangs/Nogs: Non-essential dwangs/nogs omitted. Dwangs/Nogs at corners and internal wall junctions were on edge (vertical) and aligned with the face of the internal linings. This allows continuous insulation to the outside.
In addition, services are installed more quickly as no drilling of holes is required to run plumbing and electrical vertically.

Rigid Air Barrier: Home RAB 6mm fibre cement (we no longer use this material as waste is heavy and cannot be recycled) Plywood or OSB RAB is now preferred.

Structural cavity battens: 45mm castellated timber structural cavity battens were used to eliminate the need for additional framing for cladding fixings. This also mean less penetrations of RAB and /or building wrap. We have since found 40mm Structural cavity batten are cheaper but provide the same function.

Claddings:
Two Storey, Vertical Shiplap Larch Weatherboard and UltraClad Shadoline Aluminium Weatherboard.
Single Storey, Horizontal Rusticated Cedar Weatherboard, Axon Panel, Feature Stone Veneer.

Insulation:
Glass wool R4.0
Polyester used between lintel members to reduce thermal bridging.
(Note, Sheep's Wool polyester blend was originally specified but not able to be used as at the time it did not have product certification suitable to achieve points for the Homestar rating.)

Suitable for a range of claddings? YES

Specific structural engineering required? NO
The framing required no SED Specific Engineer Design for framing. SED for foundations and stair opening.

Benefits of system:

- More insulation and less timber (better thermal performance)
- No dwang/nogs means less thermal bridging
- Vertical dwangs/nog where essential still allows continuous 90mm insulation.
- Structural cavity battens means less framing required for cladding junctions and therefore reduced thermal bridging
- LVL stronger, straighter, more stable.
- Cost neutral or slightly cheaper. (timber costs more than insulation)
- Frames slightly lighter
- Services can be run vertically without the need to drill through dwangs
- Points available for Homestar (innovation)
- Easy for builder as not too different from what they know and work with currently.

Challenges of system:

- Discussions required with frame supplier to ensure they read the plans in detail and don't just deliver standard frames as usual.
- Use of structural cavity battens required (if optimum reduction of framing desired).
- 140mm preferred for ease of foundation edge insulation detailing i.e., easy installation of hold down bolt with correct cover without need for angled bolts.
- Potentially challenging to have this adopted by builders who are resistant to changes. (not an issue for Superhome participant builders, but may be for others)

Building consent issues noted (if any): None identified
With the Church Square homes being the first (of its kind) we met with council building inspector team leader on site to talk him through what we were doing differently and circumvent any potential issue at consent processing or inspection stage. We have not encountered any consenting issues since.

Cost comparison: It is not often that improvements are actually cheaper than the status quo. Its perplexing why these methods have not been widely adopted. Timber is more expensive than insulation meaning if the ratio of insulation to timber is increased then cost savings will result. Furthermore, omitted or vertical dwang/nogs results in time saved installing services.

Wall system innovations
The GIBFIX framing system was incorporated into the 10 Star home demonstration project and then additional enhancements were also implemented that provide further improved performance.

Removing unnecessary framing e.g., non-essential dwangs/nogs were omitted and use of structural cavity battens reduced framing required for cladding fixings and junctions.
At the time (just over five years ago) this was one of the first builds to incorporate the GIBFIX system and other innovations and was used as a trial case study prior to the system being released to the market. We thought this method would be widely adopted and become the new normal as it provides better

performance and is cost neutral. Unfortunately, these techniques have not been widely adopted. Therefore, for the reasons stated above it may be a good example to become a new acceptable solution.

Replacing triple or stud-block-stud arrangements at wall junctions with ‘frame saver’ metal angles, means less timber is used increasing the **thermal efficiency** of the external envelope and increasing **seismic resilience** by securely locking plasterboard corners to a single metal angle. This results in better energy efficiency through more insulation and less thermal bridging due to less timber. Further cost savings are achieved as only one instead of two GIB HandiBrac® bottom plate anchors are required at corners. Another benefit is reduced risk of quality of finish imperfections as many mechanical fasteners into timber have been removed. Also included are new wall to ceiling details with similar benefits.

\The 10 Star home additionally used a RAB, Rigid Air Barrier and 140mm wide LVL framing for improved structural bracing and thermal performance. Semi-rigid insulation was added between lintel gaps and the midfloor junction was also insulated. Services penetrations were minimised and were taped both sides to make airtight. Bottom plates were sealed to the concrete floor and the 140mm bottom plate over hung 50mm from the slab edge to allow correct concrete cover for hold down bolt and an easy detail for continuous slab edge insulation. The 10-star home did not incorporate an internal airtightness barrier, nor did it have a battened internal services cavity.

The rationale of this project was to demonstrate that a high-performance home could be achieved cost efficiently and with readily available materials and methods that are easily implemented. The workshop presentation (https://youtu.be/_altm5o6jcA) also covered the importance of considering junctions to other elements when thinking about enhanced timber frame wall systems e.g., floor junctions with minimised thermal bridging and windows installed in line with the insulated part of the wall rather than in the uninsulated cladding cavity. This project was also an early prototype for recessed window details.

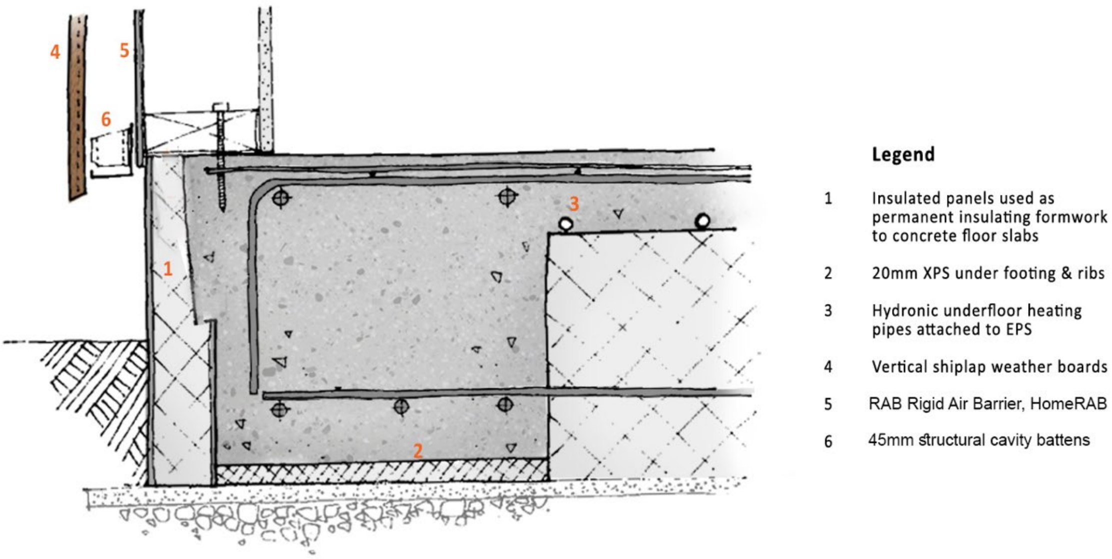


Figure 19: Illustration of foundation details showing 140mm framing and slab edge insulation

For more information please see: https://superhome.co.nz

3 Part Three conclusions

The workshop showcased several existing wall construction systems designed and deployed to overcome issues relating to thermal bridging and to deliver substantially higher R-values in the thermal envelope of walls.

These systems and approaches have been designed, approved and constructed within current compliance regimens and using reasonably standard materials. A range of different approaches have been identified, but most employ a counter-battened 'second skin' of insulation to fully break the thermal bridging resulting from the timber framing.

All the systems showcased have been successfully constructed in a number of houses dotted around the country. They have all been through local authority consenting processes and have achieved compliance. However, some have utilised specialist engineering and/or design and, in some cases, industry struggled to deliver aspects of the new construction methodology seamlessly. In addition, in some instances, local authority building compliance staff have required additional information during the consenting process and some aspects (e.g., recessed windows) further complicate consent approval.

The addition of a second layer of insulation to overcome thermal bridging of framing in standard 90mm walls constructed to NZS3604 provides a compelling solution. A number of benefits can be identified including:

- The approach could be delivered alongside existing NZS3604 design which is well known and widely understood.
- A secondary layer of insulation improves thermal performance somewhat independently of the percentage of framing required for the structural component of the wall – meaning that additional work to optimise framing in wall panels could be avoided.
- The 45mm x 45mm counter batten technique utilises standard construction materials that are commonly available including types/grades of insulation products and sizes/grades of timber.
- The frame and truss industry would be able to calculate and order the additional battening timber required which could be organised and delivered to site for builder installation (i.e., it could become part of a streamlined process).
- The additional layer on the inside of the structure can be utilised as a part-insulated service cavity to run services through, thereby further protecting the thermal performance of the overall building envelope. This approach may also reduce the labour costs of installing services such as plumbing and wiring.
- The additional layer of insulation reduces the thermal bridging across the face of the entire external wall, providing a consistent thermal envelope with a minimum of weak points and condensation prone areas.
- A secondary layer of insulation running counter to the first may also reduce air movement within the wall and thereby improve the rated performance of the insulation (in either layer).

- Larger areas of thermal bridging 'the walls of wood' encountered in many of the 47 case study examples) could be eliminated as a major source of heat loss and condensation risk.
- A second layer of insulation would help to compensate for the identified weak points in current framing and insulation practices (especially external corners, internal wall junctions, uninsulated midfloors, uninsulated fixing timbers etc).
- A second layer of insulation would help to compensate for poorly installed insulation in either layer (e.g., through compression, tucks or folds or gaps as commonly seen on-site in some of the 47 case study houses examined in Stage One of the research).

However, there is also a range of other considerations to take into account including:

- Cladding and linings manufacturer specifications: many have been designed to a standardised NZS3604 system – so any deviation from this may complicate fixings, structural integrity, weathertightness etc.
- Delivery at frame & truss: Beacon's Stage One research highlighted the fact that more than 95% of house framing is currently delivered through frame and truss suppliers. These organisations have developed streamlined efficient systems to deliver large scale framing to a busy housing market in a safe and efficient way. Any solution needs to be developed in concert with this industry so that their current efficient delivery in a busy market is not compromised
- Many of the proponents of the secondary layer of insulation approach utilise a Vapour Control Layer (VCL) or vapour barrier within their construction system. Issues relating to the potential for interstitial moisture and condensation are not sufficiently studied within the New Zealand context and the application of VCL is not common practice. Further research in collaboration with industry is required to ascertain if a VCL is required (as an example from the workshop, the Zero Energy House did not employ a VCL but Superhome wall details often include one).

There may be scope to utilise any one or all of the approaches explored in this research, but further testing is required to confirm suitability and industry acceptability. Wide-scale and broad government and industry collaboration is required to design and develop effective acceptable/alternative solutions that overcome the thermal shortcomings of our current standard 90mm NZS3604 framing design and construction.

As a minimum, this widespread collaboration should include:

- Frame and truss industry (individual companies as well as FTMA)
- Frame and truss software providers (e.g., MiTek and Pryda)
- Building product suppliers including insulation providers, timber merchants, cladding and linings manufacturers
- MBIE (especially Building System Performance) and leads of all relevant code clauses
- EECA, BRANZ and building research institutions, incl. structural/weathertightness experts
- ADNZ, NZIA, and other design and training organisations
- Designers, engineers, builders, construction companies, consultants (e.g. Superhomes Movement, PHINZ, volume home builders, NZGBC)
- Kāinga Ora and other large housing providers
- BCITO and other education providers
- Territorial authorities, building officials and building consent teams

Research findings: Summary and conclusions

Exploring current percentages of framing

Impacts of framing, weak points and blind spots

Advanced framing & insulation solutions

This report provides results and insights from the BRANZ Levy funded project *"Thermal bridging in timber-framed walls in New Zealand: Stage Two"* which is Stage Two of *'The Wall Project'*. The research has been presented in three parts and each plays a role in exploring the causes, impacts and possible solutions to the high percentages of framing and other design and construction issues encountered in Stage One of the Wall Project[25].

The research specifically set out to answer the following key research questions:

Research questions:

1. *Which of the identified key drivers for high framing ratios are responsible for the largest amount of additional framing?*
2. *Can framing design be optimised to reduce wall framing ratios and, subsequently, reduce the effects of thermal bridging?*
3. *What are the modelled thermal performance impacts of the higher ratios of framing encountered when compounded by the weak points and blind spots in the thermal envelope that have been identified in typical current construction practices?*
4. *What are the practical advanced framing solutions in new build construction that can improve thermal performance of timber frame walls?*
5. *Are these solutions buildable, cost effective and feasible from a compliance point of view?*

Stage Two of the research explored these questions through interrelated programmes of work that focussed on the following three key areas:

1. **Exploring drivers of current percentages of framing** – deepening our understanding of the drivers: working with frame and truss detailers to identify the drivers of the high percentages of framing and exploring optimisation of typical design and construction.

[25] See Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2020). Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand. BRANZ external Research Report ER53 (Report Wall/3 from Beacon Pathway Inc.)

2. **Impacts of high framing content, weak points and blind spots** – deepening our understanding of the impacts of the higher percentages of framing encountered. Assessing and quantify the impact of both the high framing ratios and the identified weak points/blind spots on the performance of the thermal envelope through modelling.
3. **Advanced framing and insulation solutions** – exploring practical ideas for improvement of the thermal envelope: identifying advanced framing and insulation options, and holding a workshop to explore whether these could be adapted to modify existing 'typical' framing solutions.

Conclusions from the research can be directly mapped against the original questions posed at the start of the research:

Research Question 1: Which of the identified key drivers for high framing ratios are responsible for the largest amount of additional framing?

Research outlined in Part One answers this question through analysis of a simple standard housing design tailored to explore drivers for different percentages of framing. Analysis shows that there is no single factor that over-rides others in respect to the higher-than-assumed rates of framing encountered in typical housing of the present day. A range of variables is explored and, as the research shows, it is more a case of 'death by a thousand cuts' with each variable adding small percentages of timber on top of others.

Importantly, analysis of current detailing techniques suggests that there is little in the way of 'unnecessary' timber being added to framing. Each piece of 90mm x 45mm timber is added to the frame and the wall for reasons relating to structure, weathertightness, and to supply fixings for cladding, linings and additional fittings. It is beyond the scope of this research to analyse the suitability and/or appropriateness of specifications detailed in standards such as NZS 3604 or requirements from cladding manufacturers, or particular approaches taken to achieve compliance levels of weathertightness (such as cavity construction) etc.

Research Question 2: Can framing design be optimised to reduce wall framing ratios and, subsequently, reduce the effects of thermal bridging*?*

Part One of this research involved the expertise of one of New Zealand's most experienced frame and truss detailers. Even with a relatively simple house design, and utilising several expert workarounds, the final percentage of framing could not be reduced from the original 'basic' detailing to a level below a 25% percentage of framing.

The research indicates that within the current confines of existing standards, building code clauses, specifications, and exploring a range of typical cladding types, wind zones, construction requirements etc; optimising the percentage of framing in standard 90mm walls will not lead to a sufficient enough decrease in percentages of framing (and thermal bridging) to achieve the intention of basic NZ Building Code construction R-value minimums.

Research Question 3: What are the modelled thermal performance impacts of the higher ratios of framing encountered when compounded by the weak points and blind spots in the thermal envelope that have been identified in typical current construction practices?

Part Two of the research outlined in this report answers this question through modelling of five sample houses drawn from the original data set of 47 case study houses explored in Stage One of the Wall Project. The results highlight a number of key insights:

- The sample houses, all of which complied with the NZ Building Code, had resulting wall construction R-values less than R1.5 (with a range of R1.2 – R1.4), even if constructed with R2.8 insulation installed. (It should be noted that these R-values will be closer to the actual construction R-values than the simplified 'clear wall' analysis provided for in H1/AS1 (NZS 4218); and it is worth stressing that the two calculation methods cannot be directly compared – please see **Framing and thermal bridging definitions – an explanatory note** in this report).
- Overall thermal resistance of external walls (as-built via modelling) is well below recommended levels set out in NZ Building Code Clause H1 and also below the required minimum of R1.5 set out in Building Code Clause E3 (noting once again the difference in methodology to determine construction R-values as set out in H1/AS1 (NZS 4218))
- Wall panels with large areas of thermal bridging and a variety of weak points will result in a pathway for excessive heat loss and therefore present a condensation and mould risk
- The largest single increase in wall construction R-value identified in the sample is attributed to the floor slab edge being insulated. Insulating the floor slab edge <u>on single level houses</u> improves the whole house wall construction R-value by around **40%**
- Upgrading the five typical weak points together produces a much smaller increase in wall construction R-values. For walls with R2.2 insulation installed, the increase is **11%**
- When the five weak points and external floor slab edge insulation is addressed the increase in averaged whole house wall construction R-value for the 5 sample properties is 55% (modelled with R2.0 insulation), 58% (R2.2 insulation) and 68% (R2.8 insulation). The majority of the increase (80%) is due to the slab edge being insulated.
- If it were possible to limit the percentage of wall framing to 25% (from an average of 32% across the five house sample), this would only have a small positive impact on wall system R-value resulting in an overall wall R-value increase of 6% for R2.0 insulation and 8% with R2.8 insulation. This is still well below the intention of NZ Building Code Clause H1 and only just achieves NZ Building Code Clause E3 (minimum R1.5) with R2.8 insulation.
- Given the challenges involved in reducing framing percentages and the relatively small R-value gains of reduced framing ratios in a typical 90mm stud wall, reducing framing <u>on its own</u> is a limited strategy. Similarly, increasing insulation to R2.8 and applying upgrades of 5 common weak points (5Up) <u>on their own</u> will not produce walls with construction R-values over R1.80, even with framing limited to 25%.
- Thermal bridging through the timber framing is not ultimately addressed by an approach that simply upgrades weak points and attempts to reduce the percentage of framing. Thermal bridging, even in an upgraded wall, will continue to be a source of heat loss and a potential location of condensation and mould.

Research Question 4: What are the practical advanced framing solutions in new build construction that can improve thermal performance of timber frame walls?

Part Three of the research addressed this question through an interactive online webinar with a targeted audience of industry and government representatives and stakeholders. Several real-world examples of systems that have been designed, consented and built were showcased. Most of the construction approaches attempted to overcome issues relating to thermal bridging through the application of a 'second skin' of insulation over a reasonably standard 90mm stud wall. There were several benefits of this approach outlined and more detail and discussion is available in the recording from the webinar available here: https://youtu.be/SNrM6HHLtgA

Research Question 5: Are these solutions buildable, cost effective and feasible from a compliance point of view?

This final question was partly addressed through the research and was informed by the online workshop and subsequent discussions.

The solutions identified are certainly buildable as is evidenced by the majority of presenters highlighting houses under construction utilising these systems.

They are also cost effective as is evidenced from examples such as the Superhome Movement who are currently involved in several construction projects that are underway and utilising a variety of additional insulation layer systems. Similarly, the examples provided by Oculus, who are pursuing a number of medium density construction projects that utilise an external layer of insulation to overcome thermal bridging suggest that cost effectiveness has been addressed.

The identified solutions appear to be feasible from a compliance point of view – with all of the systems showcased having been through a variety of consenting and approvals process. It would be worthwhile pursuing the additional work required to deliver them as acceptable solutions within the parameters of the current compliance regimen.

Discussions during the workshop, and subsequently with a variety of industry stakeholders afterward, suggests that for these solutions to be adopted widely and achieve uptake at scale throughout New Zealand, a much more involved and wider industry/government collaboration is warranted.

The research findings and insights outlined in this report have the potential to inform changes to building regulation and the codes governing the design and construction of external walls in New Zealand's residential sector. The path toward an improved thermal envelope and warm, dry resource efficient New Zealand homes requires collaborative effort as well as a substantial cultural change from all stakeholders in our residential construction sector.

Overall conclusion

In exploring the reasons for the apparent high rates of framing in New Zealand construction, the research has come to the conclusion that most of the framing is there for good reason and the majority of it relates to structure and weathertightness. Essentially, to talk of 'high rates of framing' or 'unnecessary framing' is incorrect use of the terminology; the level of framing in walls discovered in Stage One (an average 34%) and the level of framing typical to even a simple house (approx. 30%) is a direct result of the way we design and construct standard 90mm stud walls in New Zealand, and the majority of the timber in our walls is there as a result of NZ Building Code Clauses B1 (structure) and E2 (weathertightness) requirements.

Efforts to reduce the framing through optimisation of the detailing process have shown that it is very difficult to get below 25% framing - even for a relatively simple single storey dwelling of modest dimensions.

Thermal modelling of typical houses shows that the amount of framing - and therefore thermal bridging in standard 90mm walls - is resulting in construction R-values that are much lower than appears to be the intention of New Zealand regulations dealing with thermal performance and energy efficiency. The research highlights that, **even if** the percentage of framing could be reduced to 25% (a big challenge), and **even if** insulation R-values are improved and **even if** they could be installed correctly, **and even if** all the weak points are dealt with, then it still would not be sufficient to overcome the negative effects of thermal bridging and improve construction R-values sufficiently to achieve the intentions of NZ Building Code Clause H1/AS1 which calls for wall construction R-values above R1.9/R2.

This highlights that a new approach to construction of walls is required - and some promising examples have been explored. However, the reality is that this presents a complex challenge that needs to be addressed - and a collaborative and collective effort across industry and government is required to design and implement a better wall construction methodology in New Zealand.

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Appendix One: Modelling results summaries

Table 5: Full primary results table

Appendix 1: FULL PRIMARY RESULTS TABLE <u>Wall System</u> R-Values				S1 Basecase (As-Built with Weakpoints)			1UP 1 x Weakpoint Upgraded (Floor slab edge Insulated)			5Up 5 x Weakpoints Upgraded (Insulate - ExtCnr; IntCnr; IWJ; Top-plate; Midfloor)			6Up 6 x Weakpoints Upgraded (All 6 weakpoints)		
House	**Level**	**Floor Area m2**	**Framing %**	**S1(2.0)**	**S1(2.2)**	**S1(2.8)**	**1Up(2.0)**	**1Up(2.2)**	**1Up(2.8)**	**5Up(2.0)**	**5Up(2.2)**	**5U(2.8)**	**6Up(2.0)**	**6Up(2.2)**	**6Up(2.8)**
HSE-1	L1	110	**32%**	1.24	1.27	1.38	1.90	2.00	2.27	1.35	1.40	1.52	2.18	2.32	2.69
			25%	1.32	1.38	1.52	2.14	2.26	2.67	1.45	1.52	1.70	2.47	2.68	3.27
HSE-2	L1	145	**26%**	1.32	1.38	1.49	1.86	2.10	2.38	1.47	1.54	1.68	2.16	2.30	2.65
			25%	1.35	1.39	1.55	1.91	2.14	2.53	1.50	1.56	1.76	2.23	2.35	2.83
HSE-3	L1	144	**35%**	1.24	1.28	1.38	1.76	1.84	2.05	1.37	1.41	1.54	2.02	2.13	2.42
			25%	1.35	1.41	1.55	1.99	2.12	2.46	1.50	1.57	1.75	2.34	2.51	3.00
HSE-4	L1	55	**31%**	1.23	1.27	1.37	1.61	1.67	1.86	1.34	1.39	1.51	1.80	1.88	2.11
			25%	1.34	1.30	1.54	1.71	1.86	2.17	1.45	1.52	1.71	2.01	2.12	2.52
	L2	60	**29%**	1.35	1.40	1.53	1.42	1.47	1.62	1.53	1.59	1.77	1.62	1.70	1.90
			25%	1.42	1.47	1.64	1.50	1.55	1.75	1.62	1.69	1.92	1.73	1.80	2.07
	Whole House (Levels Combined)	115	**30%**	**1.29**	**1.34**	**1.45**	**1.51**	**1.57**	**1.74**	**1.44**	**1.46**	**1.64**	**1.71**	**1.78**	**2.00**
			25%	**1.38**	**1.39**	**1.59**	**1.60**	**1.70**	**1.95**	**1.54**	**1.61**	**1.82**	**1.86**	**1.95**	**2.29**
HSE-5	L1	70	**32%**	1.26	1.30	1.35	1.74	1.82	2.05	1.38	1.43	1.49	2.02	2.13	2.45
			25%	1.33	1.37	1.45	1.88	1.97	2.29	1.47	1.52	1.62	2.21	2.34	2.87
	L2	71	**36%**	1.14	1.17	1.27	1.20	1.24	1.34	1.30	1.34	1.45	1.37	1.42	1.55
			25%	1.22	1.26	1.40	1.29	1.34	1.49	1.40	1.45	1.63	1.49	1.55	1.75
	Whole House (Levels Combined)	141	**34%**	**1.21**	**1.24**	**1.31**	**1.47**	**1.53**	**1.69**	**1.34**	**1.38**	**1.47**	**1.69**	**1.77**	**2.00**
			25%	**1.27**	**1.32**	**1.42**	**1.58**	**1.65**	**1.88**	**1.43**	**1.49**	**1.62**	**1.85**	**1.94**	**2.30**

Table 6: Whole house wall system R-values with different insulation and upgrade levels

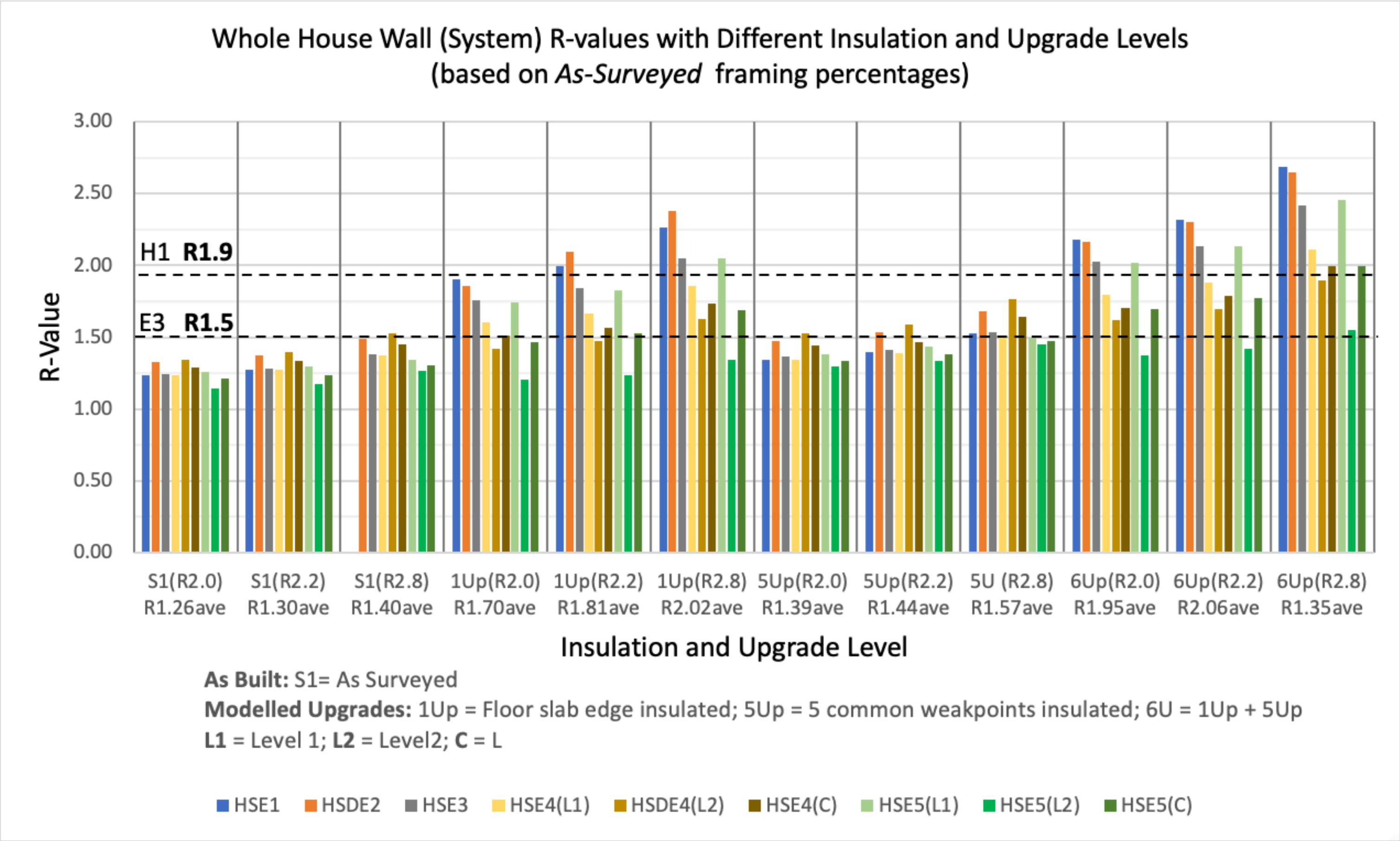

Table 7: Volume-derived vs area-derived wall panel framing percentages

Volume-Derived vs Area-Derived Wall Panel Framing Percentages									
	Volume-Derived (F & T Data)				**Area-Derived (Research Data)**				
Panel	**Act.Cube (m^3)**	**Gross Wall m^3**	**Net Wall m^3**	**Framing Percentage**	**Wall Area M2**	**Framing Area**	**Framing Percentage**		**Difference**
E1	0.29	1.28	0.76	**37.63%**	8.48	3.19	**37.64%**		0.01%
E2	0.07	0.26	0.09	**76.62%**	0.99	0.74	**75.40%**		-1.22%
E3	0.19	0.69	0.49	**38.02%**	5.50	2.09	**38.02%**		0.00%
E4	0.35	1.25	0.96	**36.21%**	10.70	3.88	**36.22%**		0.01%
E5	0.23	0.78	0.69	**33.08%**	7.70	2.55	**33.09%**		0.01%
E6	0.16	0.76	0.76	**20.83%**	8.48	1.77	**20.84%**		0.00%
E7	0.25	0.85	0.65	**38.55%**	7.19	2.77	**38.55%**		0.00%
E8	0.13	0.44	0.23	**54.73%**	2.56	1.40	**54.73%**		0.00%
E9	0.18	0.64	0.52	**34.93%**	5.49	1.98	**36.08%**		1.15%
E10	0.17	0.61	0.45	**38.47%**	5.03	1.94	**38.48%**		0.01%
E11	0.21	0.91	0.73	**29.40%**	8.09	2.38	**29.41%**		0.00%
E12	0.22	0.98	0.98	**22.26%**	10.87	2.42	**22.26%**		0.00%
E13	0.14	0.57	0.39	**37.02%**	4.34	1.61	**37.02%**		0.01%
E14	0.05	0.11	0.11	**48.82%**	1.25	0.61	**48.84%**		0.02%
E15	0.05	0.12	0.12	**46.22%**	1.26	0.61	**48.57%**		2.36%
E16	0.06	0.15	0.15	**38.36%**	1.69	0.65	**38.36%**		0.00%
E17	0.06	0.15	0.15	**38.36%**	1.69	0.65	**38.36%**		0.00%
TOTAL	2.81	10.56	8.25	**34.12%**	91.32	31.24	**34.21%**		**0.08%**